THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Participating in Energy Systems through Everyday Designs

Exploring roles for households in a more sustainable energy future

SARA RENSTRÖM

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Industrial and Materials Science
Division Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
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SARA RENSTRÖM
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ABSTRACT

As households we participate in energy systems when, in the course of our everyday energy-reliant activities, we create a demand for energy and when we engage in energy-managing activities such as choosing an energy provider and deciding to support a specific source of energy. In this way, everyday life has an impact on the energy sector, and vice versa. To mitigate climate change, the energy sector will have to reduce its negative environmental impact, and everyday life will have to change with it. This thesis aims at contributing to development of artefacts that, as they are embedded into energy-reliant and energy-managing activities in everyday life, support such changes. Four empirical studies were carried out in a research through design process with a 'mixed methods' approach. Two studies described which energy-reliant and energy-managing activities to design for by identifying what roles households could play in energy systems (RQ 1a). Two studies explored how artefacts shape those roles (RQ 1a) and prescribed ways to design to support reduced negative environmental impact (RQ 2).

The findings showed that the roles households considered playing in energy systems were framed by (i) roles performed by peers, (ii) available and accessible energy-reliant and energy-managing artefacts, (iii) existing business models, (iv) available infrastructure, and (v) policy and regulation. The roles were framed into three so-called meta-roles named Reception, Interplay, and Balance.

Within Reception, households receive standardised amounts and variants of services from the energy system, such as a pre-set indoor temperature. Within Interplay, the households' meta-role is to use some kind of interplay with the energy system to optimise energy services for their individual preferences, for example low cost. Finally, within Balance, the households' meta-role is to balance their individual preferences with what is preferable from an energy system perspective, for instance without benefits to be part of time-shifting energy use to cut peaks in demand.

In Reception and Interplay, the reduction in environmental impact is restricted to either what can be achieved without households' active contribution or when reductions in environmental impact align with personal preferences, respectively. Balance, although uncommon and therefore unvalidated, was therefore considered most promising to mitigate climate change.

Evaluations of two prototypes intended to support reduced negative energy-related environmental impact showed such possibilities, and additionally that Reception and Interplay could be challenged by designing artefacts that:

- encourage households to make compromises and ask for efforts;
- make the connection between energy supply and demand explicit (reconnecting supply and demand);
- provide a possibility to feel like active participants (instead of discouraging active participation through automation);
- provide a possibility for influencing energy-related decisions made by energy companies or (local) authorities; and
- focus on energy-reliant activities and not (only) on energy-managing activities.

Artefacts are however just one of the five aspects found to frame meta-roles. In order to not only *challenge* but also *change* a prevailing meta-role, the other aspects would need to align.

Keywords: energy use, user-centred design, smart energy, smart home, sustainable energy systems, sustainable design, demand-side management

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APPENDED PUBLICATIONS

PAPER X

Selvefors, A., Strömberg, H., & Renström, S. (2016). *What a Designer Can Change: A proposal for a categorisation of artefact-related aspects*. Paper presented at the DRS 2016: Future Focused Thinking. Brighton, UK.

Contribution: Selvefors and Strömberg conceived the original idea for the paper. Selvefors, Strömberg, and Renström developed the idea further and wrote the paper together. More specifically, Renström performed the literature review of similar theories that supported the main idea in the paper and was responsible for writing that part of the paper.

PAPER A

Renström, S., & Rahe, U. (2013). *Understanding Residents' Use of Heating and Hot Water – An exploration of the potential for reduced energy consumption.* Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies. Istanbul, Turkey.

Contribution: Renström planned the study in the paper, carried out the study, analysed the data, and wrote the paper. Rahe reviewed the paper.

PAPER B

Renström, S., Strömberg, H., & Rahe, U. (2017). *Design for Alternative Ways of Doing - explorations in the context of thermal comfort.* Journal of Design Research, 15(3-4), 153-173.

Contribution: Renström planned the study in the paper, carried out the study, and analysed the data. Strömberg advised during the study. Renström and Strömberg wrote the paper. Rahe reviewed the paper.

PAPER C

Renström, S. (2019). *Supporting Diverse Roles for People in Smart Energy Systems*. Energy Research & Social Science, 53, 98-109.

Contribution: Renström planned the study in the paper, carried out the study (with assistance from colleagues), analysed the data, and wrote the paper.

PAPER D

Renström, S., Andersson, S., Jonasson, A., Rahe, U., Merl, K., & Sundgren, M. (2019, accepted by abstract). *Limit My Energy Use! An In-Situ Exploration of a Smart Home System Featuring an Adaptive Energy Threshold*. Paper accepted for presentation at the 19th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP): Circular Europe for Sustainability – Design, Production and Consumption. Barcelona, Spain.

Contribution: Renström, Merl, Sundgren, and Andersson designed the smart home system, with input from Rahe. Jonasson led the prototyping of the system. Renström planned the evaluation study in the paper and carried it out together with Andersson and Jonasson. Renström analysed the data together with Andersson. Renström and Andersson wrote the paper together. Jonasson, Rahe, Merl, and Sundgren reviewed the paper.

ADDITIONAL PUBLICATIONS

Lidman, K. M. E., Renström, S., & Karlsson, I. C. M. (2011). *The Green User. Design for sustainable behaviour.* Paper presented at the IASDR Conference 2011, Diversity and unity. Delft, the Netherlands.

Lidman, K. M. E., Renström, S., & Karlsson, I. C. M. (2011). *I Don't Want to Drown the Frog! A Comparison of Four Design Strategies to Reduce Overdosing of Detergents.* Paper presented at the Sustainable Innovation 2011, 'Towards Sustainable Product Design'. Farnham, UK.

Selvefors, A., Renström, S., Viggedal, A., Lannsjö, R. & Rahe, U. (2012) *Benefits and Difficulties for Industry when Designing for Sustainable Behaviour.* Paper presented at 17th International Conference on Sustainable Innovation: Towards Sustainable Product Design. Bonn, Germany.

Renström, S., Selvefors, A., Strömberg, H., Karlsson, I.C. M. & Rahe, U. (2013). *Target the Use Phase! Design for Sustainable Behaviour.* Paper presented at the 6th International Conference on Life Cycle Management. Gothenburg, Sweden.

Renström, S., Strömberg, H., & Selvefors, A. (2013). *Pathways of Sustainable Behaviours.* Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies. Istanbul, Turkey.

Renström, S., & Rahe, U. (2013). *Pleasurable Ways of Staying Warm.* Paper presented at the IASDR Conference 2013: Consilience and Innovation in Design. Tokyo, Japan.

Lockton, D., Renström, S., Bowden, F., Rahe, U., Brass, C., & Gheerawo, R. (2014). *Energy storytelling through annotating everyday life.* Paper presented at the Behave Energy Conference 2014. Oxford, UK.

Lockton, D., Renström, S., Bowden, F., Rahe, U., Brass, C., & Gheerawo, R. (2014). *Narrating energy through annotating everyday life.* Paper presented at the Royal Geographical Society 2014 Annual International Conference. London, UK.

Selvefors, A., Renström, S., & Strömberg, H. (2014). *Design for sustainable behaviour: a toolbox for targeting the use phase.* Paper presented at the Eco-design tool conference 2014, Swerea. Gothenburg, Sweden.

Strömberg, H., Selvefors, A., & Renström, S. (2015). Mapping out the design opportunities: Pathways of sustainable behaviour. *International Journal of Sustainable Engineering, 8*(3), 163-172.

Selvefors, A., Rexfelt, O., Strömberg, H., & Renström, S. (2018). *Re-framing Product Circularity from a User Perspective.* Paper presented at the DRS2018: Catalyst. Limerick, Ireland.

Selvefors, A., Rexfelt, O., Renström, S., & Strömberg, H. (2019). *U*se to use – A user perspective on product circularity. *Journal of Cleaner Production, 223*, 1014-1028.

TERMINOLOGY AND ABBREVIATIONS

Artefact	Something manmade, either something tangible (e.g. a product) or intangible (e.g. a service) or a combination of the two (e.g. a product-service system).
Decarbonisation	The reduction or removal of carbon dioxide from energy systems often by either using non-fossil sources of energy or by capturing and storing carbon dioxide emissions.
District heating	A socio-technical system that moves thermal energy (i.e. heat), from available heat sources to the users of heat, such as residents, where it is used both for space heat and hot water.
Doings	An umbrella term used to denote what people do without theoretical connotations. Doings refer jointly to behaviours, activities, actions, and practices (cf. Selvefors, 2017).
Energy company	A company that generates, distributes, and/or sells energy and energy-related services.
Energy-efficient technology (or design/tool/product/artefact/solution/service)	Technology developed with the intention of using less energy to produce the same (or similar) outcome and that lives up to the intention (at least to some extent).
Energy-related services	Services that energy utilities can provide as a complement to the energy they sell, e.g. services that help their customers to improve energy efficiency.
Energy-reliant activity	An activity that needs energy to be carried out but in which energy features just as a means and is not related to the activity's motive or intended outcome.
Energy-reliant artefact (or design/tool/product/technology/solution/service)	An artefact that needs energy when being used, but energy features just as a means and is not related to the artefact's main purpose. Households typically have their own or rent (e.g. as a part of renting an apartment) energy-reliant artefacts and have some choice over which artefacts to use. Infrastructure is not considered an energy-reliant artefact in this thesis.
Energy-managing activity	Activity in which energy or the energy system is related to the activity's motive or intended outcome. Energy can also feature as a means in such activities (e.g. paying energy bills with an energy-reliant product).
Energy-managing artefact (or design/tool/product/technology/solution/service)	An artefact whose main purpose is related to energy or the energy system. There are usually fewer energy-managing artefacts than energy-reliant artefacts in a household. Households typically have (access to) energy-managing artefacts in their homes and have some choice over which artefacts to use. Infrastructure is not considered as an energy-managing artefact in this thesis.
Energy market	A market that deals with the trade and supply of energy.
Energy service	The service for the end-user that energy provides, for example heating, cooling, and power.

TERMINOLOGY AND ABBREVIATIONS CONTINUED

Energy system	A socio-technical system that fulfils several important societal functions such as energy provision (cf. Geels, 2005; Schot et al., 2016)
Energy use/consumption and heat use/consumption	Although energy and heat cannot actually be consumed, the two words 'consumption' and 'use' are used synonymously to denote when energy or heat is being used for a specific purpose.
Energy utility	An organisation that generates, distributes, and sells energy generally in regulated markets. Many energy utilities in Sweden are municipal companies.
Everyday activities	Activities people perform, often and seldom, as part of what can be considered ordinary life (i.e. not extreme life situations). These may be energy-reliant activities, energy-managing activities and activities that are not related to energy.
Excess heat	Recovered heat from industrial processes and fuel refineries that can be utilised for instance in district heating systems.
GDPR	General Data Protection Regulation, a regulation on data protection and privacy for individuals in the European Union
Household	A (part of a) building that constitutes a home, the technical products and systems in the home, and the occupants of the home regarded as one unit. With this definition a household can be seen as a socio-technical system.
Householder	A person in the capacity of being part of a household.
ICT	Information and communication technologies, technologies that collect, receive, and send information.
Infrastructure	Large-scale structures or facilities required for societal functions, such as energy provision. Infrastructure is shared by many households and is time-consuming and costly to re-build. Households do not own infrastructure and can only use the infrastructure that is made available to them.
Innovation	Technologies, organisational arrangements, and/or ways of doing that are new to a specific context (and not only new to the world) (cf. Geels et al., 2018). A district heating system is in this way of using the word an innovation if it is new to a city.
Interaction	Reciprocal action(s) or influence between people and artefacts (cf. Selvefors, 2017).
Low-carbon innovations/ socio-technical systems/ technologies	(New) technologies, organisational arrangements and/or ways of doing that are expected to facilitate decarbonisation of the energy system by increasing energy efficiency, reducing energy demand, and/or increasing demand flexibility.
Meta-role in energy system	General roles in energy systems that overarch the specific roles householders consider and perform in energy systems (see also Chapter 4).

More sustainable energy system/future	It is not easy to determine when (if ever) we have reached a truly sustainable energy system/future. I therefore prefer to mainly use the term "more sustainable energy system". With that, I mean an energy system that has less negative impact on the climate, land use, biodiversity, depletion of natural resources, and human health than the energy system that we have today.
N.a.	Not applicable
N.d.	No date
People/person	Person(s) in no specific capacity.
Person heating	Heat directed to people's bodies (e.g. hot water bottle), in contrast to space heating that predominately heats the air in a space (e.g. radiators) (Kuijer & de Jong, 2012)
Private (detached/semi-detached/terraced) house	A private detached, semi-detached, or terraced house where the residents own the house, usually intended for one household.
Power	The rate of producing or consuming energy. Power equals energy divided by time. Energy equals power multiplied by time.
PV panels	Photovoltaic solar panels (see also solar panels)
Role in energy system	If, how, and with what outcomes people want to influence the energy system (see also Section 2.1.3).
RQ	Research question
Script	Designers inscribe scripts into artefacts that 'prescribe' specific forms of action (Akrich, 1992; Verbeek, 2005).
Smart energy system	Energy system which, through the inclusion of ICT, can collect, receive, send, and interpret information about energy supply, distribution, and use.
Smart home	A home in which appliances, devices, and functions can be controlled remotely via Wi-Fi, Bluetooth, etc.
Socio-technical systems	Small (e.g. email) or large (e.g. energy system), simple or complex systems spanning hardware, software, personal, and community elements (cf. Whitworth & Ahmad, n.d.).
Solar panel	Panel that collects energy from the sun, often a photovoltaic solar panel (PV panel) that converts sunlight into electricity or a solar thermal collector that converts sunlight into heat.
Tacit efficiency	Resource efficiency that eliminates harmful environmental effects in an unobtrusive and tacit way, intended to render user cooperation irrelevant (Latour, 1992, p. 230 as cited in Brand & Fischer, 2013).
Thermal energy	A synonym for heat.
User	A person in the capacity of using an artefact or energy.
Vehicle-to-grid	Electric vehicles that can return energy to the energy system or throttle their charging rate during peaks in energy demand.

TABLE OF CONTENTS


Göteborg Energi

1 INTRODUCTION

This thesis's introductory chapter highlights how reducing energy use and increasing the share of renewable energy sources are crucial for mitigating climate change. It goes on to describe how low-carbon innovations within the energy sector are important but need to be both adopted and appropriated by end-users. In short, this thesis therefore aims to increase knowledge about and contribute to the development of socio-technical systems that, when they are embedded into everyday life, support reduced negative energy-related environmental impact. The chapter continues by introducing those research questions that have guided the work and finishes with a demarcation of the research.

1.1 BACKGROUND

Households participate in energy systems when in the course of everyday activities such as staying warm or doing dishes, they create a demand for a specific type of energy (electricity or heating, for instance) at a specific time. Households also participate in energy systems when they choose a specific energy provider and thereby support a source and method of energy supply, or when they install solar panels. In this way, everyday life impacts energy systems and vice versa; the possibilities provided by energy systems – manifested in all the artefacts designed to fit with current energy systems – impact everyday life. *Households thus participate in energy systems through everyday designs*. To mitigate climate change, the energy sector will however have to change to reduce its negative environmental impact. This thesis will explore whether everyday life too would have to change, and what such a change would entail.

Energy production and the connected greenhouse-gas emissions, including carbon dioxide contribute significantly to the ongoing climate change (IEA, 2015; IPPC, 2014), one of the most critical question of our time. In 2014, the energy sector accounted for roughly two-thirds of all anthropogenic greenhouse-gas emissions (IEA, 2015) due the sector's extensive use of fossil fuels. Since 2014, energy-related carbon dioxide emissions have risen to a historic high in 2018 (IEA, 2019). Globally, energy used in households constitutes one-fifth of the total energy used (OECD/IEA, 2018). In Sweden, the context for the research presented in this thesis, 23% of total energy use is by households (Swedish Energy Agency, 2019 (statistics covering 2017)). Efforts to decarbonise the energy sector as a whole, and energy use in households as part of this process, are therefore of utmost importance for mitigating climate change. Goal seven "Affordable and clean energy" is correspondingly one of the seventeen Sustainable Development Goals adopted by the United Nations to promote prosperity while tackling climate change and ensuring environmental protection (United Nations, n.d.-a). Targets related to goal seven of particular relevance for Sweden where most people have access to affordable energy are to "by 2030 increase substantially the share of renewable energy in the global energy mix" (target 7.2) and "by 2030, double the global rate of improvement in energy efficiency" (target 7.3) (United Nations, n.d.-b). How can these targets be met?

Innovation efforts within energy technologies intended to decarbonise the energy sector are often divided into energy-supply technologies and end-use technologies. "Energy-supply technologies are used to extract, process, transport and convert energy resources into a form useful to end-users. End-use technologies are used to convert energy into a useful final service like heating, mobility or communication." (Wilson et al., 2012, p. 780) The latter includes improving energy efficiency, such as fuel-efficient vehicles, and substitutions, such as mode-shifting from car to bicycle. So far, innovation efforts within energy-supply technologies have been privileged by public institutions and policies, as well as in terms of funding (Wilson et al., 2012). Nonetheless, it has been argued that end-use technologies have greater potential for climate change mitigation as well as higher social return on investments (Wilson et al., 2012). Significant effort is therefore needed in the field of end-use innovations (Wilson et al., 2012).

For end-use innovations to have effect, whether new types of heating system or electric bicycles, they need to be diffused into society (Geels et al., 2018) to be adopted by companies, organisations, households and so on, and finally also adopted and appropriated[1] by end-users. Diffusion, adoption, and appropriation are not always straightforward and easy. First, innovations have to compete on markets that, if the innovation is radical, align better with existing solutions (Geels, 2014). Second, many end-use innovations intended to decarbonise the energy sector "…are not intrinsically attractive to the majority of consumers since they are often (initially) more expensive and perform less well on key dimensions" (Geels et al., 2018, p. 28).

Further, when applied to real-life settings, low-carbon technologies in terms of end-use innovations do not always achieve what was intended. Thermostats installed

1 In line with Babapour et al. (2018) I use 'adoption' to denote a process of individuals or collectives (e.g. organisations) to make a decision to acquire an innovation (see also Rogers, 1995) and 'appropriation' to denote the process of adopting, shaping, and then using an artefact that starts when users decide to experiment with an innovation (Carroll et al., 2002).

for instance to save energy by being programmed to reduce the set-point temperature when acceptable, are one example of an end-use technology from which the energy savings are less than predicted (as concluded after a review by Peffer et al., 2011). Additionally, for advanced low- or zero-carbon buildings there is often a gap in the performance between the actual and estimated energy use due among other reasons to a lack of understanding about the building from builders and occupants, poorly designed user control interfaces, lack of control interfaces and inadequate access to existing control interfaces, as well as incorrect assumptions about patterns of use (Gupta et al., 2013; Tuohy & Murphy, 2012). On average, households living in homes with a theoretically *low* energy use seem to consume more energy than expected (Bartiaux et al., 2006, p. 109; Sunikka-Blank & Galvin). On the other hand, people living in homes with a theoretically *high* energy use seem to compensate for this as the actual energy use is, on average, much lower (Bartiaux et al., 2006, p. 109; Sunikka-Blank & Galvin).

For the benefits of end-use innovations to be realised, these innovations first need to be diffused and adopted and then reach (or surpass!) the estimated performance as they are appropriated into the complex realities of everyday lives. To understand more about these processes, a prerequisite is to know what types of end-use technologies there are, and which types to support.

1.1.1 End-use technologies

End-use innovations do not necessarily have to relate to technical novelty as such, they can also relate to what can be called social novelty, such as mode-shifting from car to bicycle, as mentioned earlier (Geels et al., 2018). These two possibilities, technical novelty and social novelty, are related to a split in the contemporary environmental discourse into a technophilic side that favours technical solutions to environmental problems and a technosceptic side that favours efforts to change behaviours (Brand & Fischer, 2013). However, when these sides disregard each other they also disregard the possibilities of the other side, and perhaps more importantly, the potential for combining them. When faced with reality, this split in environmental discourse is regarded as too simplistic, as "the technical and the social mutually shape each other" in socio-technical systems[1] (Brand & Fischer, 2013, p. 243).

Although technical and social change are not separable (in line with argumentation by Brand & Fischer, 2013), radical changes in technology can result in minor as well as substantial social changes and substantial social change can be connected with both incremental and radical innovation (Geels et al., 2018), as exemplified in Figure 1.1.

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1 Large socio-technical systems (such as the energy system) can be described as "a cluster of aligned elements, including artefacts, technology, knowledge, user practices and markets, regulation, cultural meaning, infrastructure, maintenance networks and supply networks" that fulfil societal functions (Geels, 2005, p. 446). Both large and small (such as email) socio-technical systems can be described as spanning hardware, software, personal, and community elements (cf. Whitworth & Ahmad, n.d.).

	Substantial social changes		
Incremental technical innovation	Car sharing, bike sharing, modal shift to bicycles and buses, efficiency improvements by energy service companies	Intermodal transport systems, compact cities, passive houses, modal shift to light rail or subway system, tele-conferencing	Radical technical innovation
	Insulation, fuel-efficient conventional cars, energy-efficient household appliances	Heat pumps, LED lights, electric or fuel cell vehicles, whole house retrofit, district heating	
	Minor social changes		

Figure 1.1. *Examples of end-use innovations with different degrees of social and technical change (adapted and expanded from Geels et al., 2018).*

Among end-use innovations, incremental technical innovations with minor social changes have been favoured (Geels et al 2018), see Table 1.1. "While these are important in the short term, they face diminishing returns in the long term, since their potential for further diffusion is limited. Hence, more substantial demand reductions are likely to require more radical innovations that are presently at an earlier stage of emergence and require larger changes to existing sociotechnical systems." (Geels et al., 2018, p. 24) It is therefore important to focus on radical technical innovations, and/or substantial social changes, see Table 1.1. This thesis will focus on two technologies that could represent radical changes: district heating and smart energy systems.

District heating

District heating is a system that moves thermal energy (i.e. heat), from available heat sources to buildings, such as offices, industries, and homes, where it is used for heating and to heat up tap water. In Sweden, district heating is no longer a novelty as it is widely used, but district heating is considered a radical technical innovation in cities that do not have this facility (Geels et al., 2018). District heating has the potential to considerably decrease the use of fossil fuels in areas where the system has not been built (cf. Connolly et al., 2012), and district heating in Sweden is an example of a fast shift away from fossil fuels (Werner, 2010). District heating is an end-use innovation that requires minor social changes for households (Geels et al., 2018), after it has been built and installed.

Smart energy systems

Energy systems that integrate information and communication technology (ICT) in ways that add 'intelligence' to the system, i.e. smart energy systems, are discussed as one way to facilitate decarbonisation of the energy sector (Kensby, 2017; Mathiesen et al., 2015; Verbong et al., 2013). This 'intelligence' can be used to communicate information about issues such as peaks in supply or demand within the system, evaluate alternatives actions, and perform actions (Kensby, 2017). Examples of what can be achieved are better use of available flexibility in demand, making decisions about which energy supply method to use (e.g. electricity or district heating), and when the supplied energy has the lowest environmental impact.

In most visions and demonstrations of smart energy systems, ICT is used to make electricity systems 'smart' (Joint Research Center Smart Electric Systems and Interoperability, 2018), often referred to as 'smart *grids*' (Lund et al., 2017). However, ICT can also be used to make district heating systems 'smart' (Kensby, 2017) or combinations of electricity and district heating systems 'smart' (Mathiesen et al., 2015). The combination is often referred to as 'smart *energy systems*' (Lund et al., 2017) and is the term used in this thesis. The inclusion of several energy supply methods (e.g. electricity and district heating) into smart energy systems is preferable to further increase flexibility and to facilitate shifting to only renewable sources of energy (Lund, Østergaard, Connolly, & Mathiesen, 2017; Mathiesen et al., 2015).

In smart energy systems, residential energy users are assumed to store energy locally and use it during peaks in demand, micro-produce energy in households or local communities, sell surplus energy, have smart appliances that operate at off-peak hours, time-shift energy-reliant activities to times when it is more favourable for the energy system, and allow energy systems to use energy that a household stores to cut peaks in demand (for examples in the batteries of electric vehicles in so-called vehicle-to-grid systems) (Geelen, 2014; Katzeff, Hasselqvist, et al., 2017; Skjølsvold et al., 2015; Taljegard et al., 2019). Some of these altered or new activities can be considered to represent

- *substantial social changes*: micro-producing energy for the local community, for example, could change the relationship between households,
- *radical technical innovations*: fuel cell energy storage, for example, could be considered a radical technical innovation just as fuel cell vehicles are (cf. Geels et al., 2018), and/or
- both *substantial social changes and radical technical innovations*: vehicle-to-grid, for example, would require electric vehicles (considered a radical technical innovation (cf. Geels et al., 2018)) equipped with smart charging technology and households that accept that their vehicles cannot always be used (in practice a modal shift, considered a substantial social change (cf. Geels et al., 2018)).

1.2 AIM

District heating and smart energy systems are thus socio-technical systems that could contribute in mitigating climate change. However, to do so, these systems will first have to be diffused, adopted, and embedded into everyday life. As the diffusion and adoption processes are not necessarily straightforward (e.g. Geels et al., 2018), those processes may need to be supported, for instance financially and legally. Such support will however not be the core topic of this thesis. The process of embedding innovations into everyday life is not straightforward either, as low-carbon systems generally seem to consume more energy than intended while 'ordinary' systems seem to consume less than expected (Bartiaux et al., 2006, p. 109; Sunikka-Blank & Galvin). Low-carbon innovations should therefore be designed so that, as they are embedded into everyday life, they are better able to support low-carbon ways of living – maybe with inspiration from how non-low-carbon systems seem to exceed their estimated potential. The aim of this thesis is therefore to contribute to

- knowledge of how people embed low-carbon socio-technical systems into everyday lives and
- development of socio-technical systems that, when they are embedded into everyday life, support reduced negative energy-related environmental impact.

The first part of the aim is thus of a more descriptive nature while the second part is of a more prescriptive and prospective nature.

1.3 PREVIOUS WORK & RESEARCH QUESTIONS

As mentioned, energy systems can be understood as socio-technical systems that fulfil several important *societal functions* such as energy provision (cf. Geels, 2005; Schot et al., 2016), or that manage and facilitate different *services* – such as comfortable homes, the possibility of preserving and preparing food, and different modes of transportation – with quantifiable dimensions (e.g. service volume such as m^2 heated area) and non-quantifiable dimensions (e.g. symbolic, such as having a hospitable home) (Jonsson et al., 2011). Energy systems exist in societal systems, that is to say "a combination of material, organizational, policy, legal, social, cultural or infrastructural elements" (Joore & Brezet, 2015, p. 96). Energy systems build on product-service systems, in other words physical elements and organisational components that only together fulfil definable functions that, in turn, incorporate product-technology systems, i.e. a combination of physical objects and systems that fulfil clearly distinguishable functions (Joore & Brezet, 2015). Energy systems thus usually include different sources of energy (e.g. hydro, nuclear, wind, solar, biomass, waste, coal, and natural gas), different energy supply methods (e.g. electricity and district heating) and energy carriers (e.g. electrical batteries), and different end-use technologies (i.e. product-technology systems), as well as different cultural, social, and legal elements that together fulfil and facilitate important societal functions and services.

1.3.1 Unsustainable energy systems

The environmental impact of an energy system depends largely on what energy sources are used, where fossil sources of energy contribute for instance to climate change through emissions of carbon dioxide (IEA, 2015). Other sources of energy have other types of impact, for example hydropower and wind power influence landscapes, biofuels are a limited resource that needs to be used at a sustainable level (Mathiesen et al., 2015), and for nuclear energy uranium has to be both sourced and stored. To mitigate climate change, however, reducing the use of fossil energy sources is most critical (IPPC, 2014).

There are effectively three approaches to reducing the use of fossil fuels, or the effects of fossil fuels: shifting from fossil to non-fossil sources of energy such as renewables and nuclear energy, carbon capture and storage, and reduced energy use (Wilhite, 2013). These approaches are often complementary; reduced energy use can be a necessity for a shift to only renewable sources of energy, for example (cf. Mathiesen et al., 2015). Irrespective of the means (one or more) by which the three approaches are realised, the transformations that energy systems need to go through are so fundamental that *sustainable transitions* are needed within the energy sector (e.g. Verbong & Loorbach, 2012).

Sustainable energy transitions

Transitions are large-scale and long-term shifts from one *socio-technical regime* – in other words "a shared, stable and aligned set of rules or routines that guide the behaviour of actors on how to produce, regulate and use energy, transportation, food production or communication technologies" – to another (Schot et al., 2016, p. 2). In this transition the incumbent regime – in our case the current fossil-dependent, centralised energy system – faces problems due to macro-events and developments in society (Schot et al., 2016) – in our case climate change. As a result, socio-technical innovations can start competing with the current energy system. In time, these innovations could mature and eventually form a new socio-technical regime.

District heating is an example of a socio-technical innovation that could be part of a transition to a less fossil-dependent energy system (Geels et al., 2018). District heating in Sweden primarily uses non-fossil fuels, focusing instead on biofuels, waste incineration, and surplus heat from industry, see Figure 1.2. As a result carbon dioxide emissions are 80% lower than in European cities that use fossil fuels to heat buildings (Werner, 2010). District heating systems are to some extent integrated with the electricity sector, for instance through combined heat and power plants. Inclusion of more ICT solutions in energy systems allows for greater integration between electricity and heating systems into smart energy systems. In smart energy systems, with a high proportion of fluctuating renewable energy, district heating can be used to balance the electricity system (Mathiesen et al., 2015; Werner, 2017).

Smart energy systems are another socio-technical innovation that could facilitate a transition to a less fossil-dependent energy system, but it could also be used solely

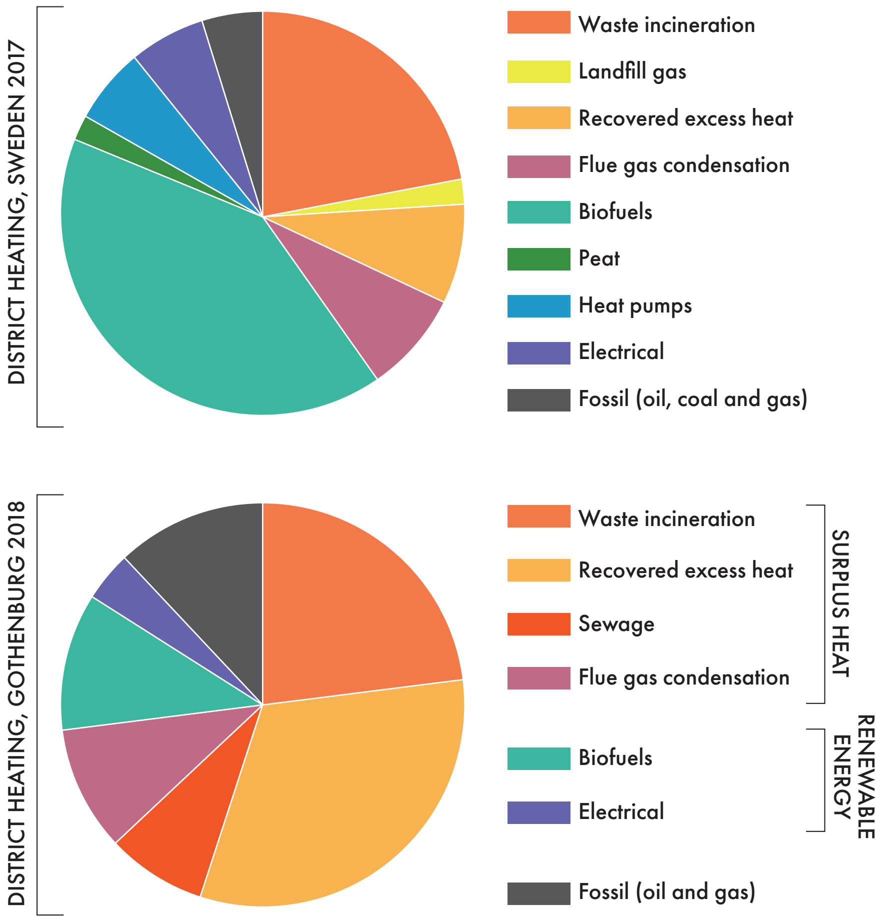


Figure 1.2. *Sources of energy in the district heating system in Gothenburg for 2018 (left) and in Sweden (right) for 2017 (Energiföretagen, 2017; Göteborg Energi, 2019).*

to optimise the current energy system (Verbong et al., 2013). Besides optimising and balancing energy systems to allow for a higher proportion of fluctuating renewable energy and thereby potentially being part of mitigating climate change, smart energy systems are also thought to facilitate for households to store energy locally and to micro-produce energy (e.g. Skjølsvold et al., 2015), thus decentralising the energy system.

To sum up, district heating and smart energy systems are two socio-technical solutions that could facilitate a transition to a less fossil-dependent and less centralised energy system. In addition, with ICT the district heating sector could be integrated with other energy sectors, such as the electricity sector, to further facilitate the inclusion of fluctuating renewable energy. For instance, in Denmark Mathiesen et al. (2015) assess that it would be possible to achieve completely renewable energy systems by 2050 through integration of different energy sectors, such as electricity and district heating, and innovating (e.g. energy storage) across sectors. Only focusing on the supply of energy, however, will not be enough: "energy savings are extremely important" (Mathiesen et al., 2015, p. 151).

Technologies and systems of supply vs. pattern of demand

One criticism of the theories of sustainable transition is that although they have a socio-technological perspective, the focus has been on *technologies and systems of supply*, and the 'socio' part has focused on the social processes that are part of technical innovation (Shove & Walker, 2010). Shove and Walker (2010) highlight the importance of also paying attention to *patterns of demand*, as emphasised by Mathiesen et al. (2015). The importance of patterns of demand is also highlighted by Schot et al. (2016, p. 1) who conclude that "despite progress toward more energy-efficient appliances, overall levels of energy consumption continue to rise". Thus, our current fossil-dependent energy system needs to transition, and district heating and ICT, by themselves and in combination, could facilitate that transition. However, as these innovations are diffused, adopted, and appropriated, the patterns of demand that follow are important. As expressed in the aim of this thesis, innovations such as these need to support an everyday with reduced negative energy-related environmental impact. The next section looks deeper into the relationship between everyday life and energy systems of relevance for this thesis: district heating and smart energy systems.

1.3.2 People's roles in energy systems (RQ 1a, 1b)

In everyday life, people do not set out to use energy (Lockton, Renström, et al., 2014; Wilhite, 2013), instead, in everyday activities energy is used as an 'ingredient' or a resource that enables an activity (Naus, 2017). With Røpke's words, (2009, p. 2495) "… people first of all think of themselves as being involved in meaningful practices rather than being involved in consumption" of energy, for example. Furthermore, energy can be described as not being used by individuals and individual devices (Wilhite, 2013) as energy use goes beyond the individual in the sense that we use energy in social contexts and share collective ideas about for what and how energy should be used. In addition, energy use goes beyond individual devices as devices are used in combination, for instance to prepare food, and their use is limited through available infrastructures. Moreover, in devices, designers inscribe their visions or predictions of the world and especially of the relationship between a device and its surrounding actors (e.g. users) (Akrich, 1992). The end-result of inscribing such ideas into a device is a *script* that devices carry with them (Akrich, 1992). Verbeek (2005, p. 125) explains the concept of script as follows.

> "This concept [script] indicates that things-in-use can 'prescribe' specific forms of action, much like the script of a theatre play, which orchestrates what happens on stage. A plastic coffee cup, for instance, has the script 'throw me away after use'; the cameras along many roads in the Netherlands

> have the script 'don't drive faster than 50 km/h'. Artifacts are not passive and inert entities. They actively co-shape what actors do."

Energy use can therefore be regarded as the "result of the interaction between things, people, knowledge, and social contexts" (Wilhite, 2013, p. 67). In everyday life energy is thus used for *something* in an activity that has both collective and material dimensions.

Energy in the background vs. the foreground

As energy is used for something, energy as such generally plays a background role in everyday life (Goulden et al., 2014). In focus groups, Goulden and colleagues found that energy usually plays a subservient role in mundane household activities. The idea that energy should in any way determine when and how people perform energy-reliant activities was alien to most focus group participants. Unlike the activities in which energy is used, energy "is 'not part of your life' and participants did not have, or want to make, time to think about energy" (Goulden et al., 2014, p. 24). Naus (2017) points to the importance of recognising and respecting the non-energy related rationalities connected to many mundane activities in and around the home, such as getting comfortable or enjoying a dinner with family or friends. In an interview study, Selvefors et al. (2015) found that the informants did have the explicit goal to reduce their energy use, but that this goal often conflicted with other and competing goals, such as the non-energy related rationalities of mundane activities (cf. Naus, 2017). The findings of Selvefors and colleagues indicate that although energy is often in the background in most everyday activities, issues concerning energy and energy use are still important to people. However, in homes, people also engage in activities in which energy is in the foreground. Naus (2017) calls this *home energy management practices* and exemplifies with reading an energy bills, installing PV panels, comparing energy use of appliances, and so on. These practices are specifically focused on managing, steering, or governing energy flows, technologies, and/or infrastructures.

There are thus activities concerned with energy in which energy use is deliberately foregrounded, and such activities will in this thesis be called *energy-managing activities*. Having said that, energy is backgrounded in most of the mundane activities that constitute everyday life. In these activities, energy is an ingredient; they are *energy-reliant activities*.

Energy use as participation in energy systems

When engaging in a mundane, energy-reliant activity we usually know that we are participating in that activity, but we do not necessarily think of ourselves as participants in the energy system. Are we indeed participating? When engaging in energy-managing activities such as switching electricity provider, participation in the energy system is perhaps more explicit and intentional; we might change electricity provider to support solar power, for instance. Nevertheless, based on Strengers (2013), Naus (2017) argues that we actively participate in energy systems in energy-reliant activities too, although not consciously or deliberately as "… when people participate in everyday practices that consume energy [...] they simultaneously draw on and reproduce the structural features of an energy system" (Strengers, 2013, p. 56). Through use of energy in activities we shape patterns of energy demand and thereby participate in energy systems, although not necessarily consciously or even deliberately (Naus, 2017).

Furthermore, over the past few decades the home has become a more explicit site for environmental action by residents. In a process that Marres (2012) describes as the 'domestication of citizenship', the domestic environment increasingly comes to function as a substitute for protests in public spaces and participation in public decision-making processes. Thus, instead of publicly voicing opinions our environmental actions are becoming more centred on the choices we make in and around the home. As part of that process, there have been numerous initiatives for merging environmental engagement with everyday activities (Marres, 2012). Initiatives include *energy-reliant activities* such as reducing indoor heating and adapting heating to the status of the energy system (e.g. Hagensby Jensen et al., 2016), designing less energy-intensive household appliances (e.g. Selvefors et al., 2018) and doing laundry off peaks in energy demand (e.g. Bourgeois et al., 2014) as well as *energy-managing activities*, such as installing PV panels. "Rather than seeking to increase people's *knowledge* about environmental issues, these initiatives focus on *action and impact* – on what people can do about the issues in question" (Marres, 2012, p. 3, emphasis in original). As a result, levels of environmental engagement and public participation are in a sense measured through everyday action – i.e. environmental action. The home with all its technologies, features, and activities thus explicitly becomes the means for people to deliberately engage in environmental issues; it becomes the scene for public participation (Marres, 2012, p. 5).

Besides participating in energy systems through energy-reliant and energy-managing activities, people can also participate in energy transition. Schot et al. (2016) found that users can *actively* facilitate energy transitions by experimenting with and innovating technologies (see also Nyborg, 2015), promoting innovations, and contribute to up-scaling and mainstreaming of innovations, for example.

To sum up, we all intentionally or non-intentionally participate in the energy system through both energy-reliant activities and energy-managing activities. In addition, such participation has in recent years explicitly started to become a means for people to engage in environmental issues – and to replace other ways of publicly voicing opinions. Lastly, one can also actively participate in energy transitions, for instance by supporting technological development in different ways. These different ways of participating can be seen as different *roles* that could be taken in the energy system.

Roles in energy systems

In everyday life, most of us take part in energy-reliant activities and can thus be said to have the role of using energy. Many of us also take part in energy-managing activities, for instance paying energy bills. As outlined earlier, the range of energy-reliant activities and energy-manging activities can be performed in different ways, and with different meanings. Energy can be backgrounded, or foregrounded, and energy-reliant and energy-managing activities can be deliberately performed to participate in energy systems, environmental action, or energy transitions. Although we all use energy, there seem to be different roles for people, and households, to play in energy systems.

Devine-Wright (2007) identified two such roles for households, or in his words two different representations of the energy public: as consumers and as citizens. In the public-as-consumer representation, developments of energy systems aim at minimising the possibilities for the public to engage. Examples are technologies that do not disrupt current ways of life designed on a ‘plug and forget’ basis. In the public-as-citizen representation developments of energy systems instead aim at maximising public engagement. Examples are small-scale technological developments, such as local energy production, and smart energy meters that rely on continuous user engagement.

In a series of focus groups with residential energy users Goulden et al. (2014) found similar roles to those of Devine-Wright (2007): energy consumers who take on the role of only being end-users of energy and energy citizens who see themselves as energy system participants. These two roles, energy consumers and energy citizens, were present in the focus groups both as what Goulden and colleagues call *personas*, meaning that they were enacted from within the focus group participants, and as *frames*, meaning that they were imposed from outside, from other actors in the energy system. For the consumer persona energy is “a good to be expended in pursuit of personal goals” while the citizen persona engage “with energy as meaningful parts of their practices” (Goulden et al., 2014, p. 24). The focus group participants did not exclusively adopt one of the personas, but many of them adopted one of them more comfortably. As the focus groups proceeded, the participants seemed to move towards the citizen persona.

van Vliet (2012) points to three roles for residential energy users: customer, citizen-consumer, and co-provider. A customer has a commercial relationship with energy providers and can choose between providers and/or services. A citizen-consumer’s relationship with energy providers is “coloured by a mutual concern about social or environmental impacts” of energy provision and consumption (van Vliet, 2012, p. 265). In the co-provider role residents produce energy and provide it to themselves and/or to others.

In homes, district heating is used to obtain centralised heating and hot water with lower environmental impact than with fossil fuels, in a way that is convenient for the householder. When radiators through which the heating is delivered are equipped with thermostatic radiator valves, as they often are, there are not many tasks for householder; district heating is a care-free system in which energy is backgrounded, apart from when energy bills are being paid. District heating seems to have been designed with energy consumers in mind. Smart energy systems, on the other hand, are often designed for an active and/or interested user, for example a user who wants to adapt energy demand to the current energy supply. Smart energy systems and accompanying technologies seem to be designed for what Strengers (2014) calls 'Resource Man': a person who is interested in energy and energy use, wants to optimise energy use, and wants to use energy-efficient technologies.

The roles that district heating systems on the one hand and smart energy systems on the other hand seem to expect households to play are thus quite different from each other. Should householders therefore play different roles in different systems? If so, what roles to play when district heating is integrated into smart energy systems? On what householders are these expectations based? Do these expectations leave enough room for diversity between households? These uncertainties underline the need to explore these roles in more detail. The first research question is therefore concerned with the role householders could play in these energy systems:

RQ 1a. What roles could householders, in their everyday lives, play in district heating systems, smart energy systems, and combinations of the two?

Comments to RQ 1a. The word 'role' is used here to denote if, how, and with what outcomes householders want to influence the energy system. 'Householder' refers to a person in the capacity of being part of a household.

The word 'could' is here chosen instead of 'want' as I am interested not only in the roles householders already think of and therefore are able to articulate, but also the roles they are not articulating as roles but that might be implied in their responses and doings. The word 'should' is not chosen as that would have suggested that some roles are inherently better than others.

Shaping roles in energy systems

When playing the roles, householders engage in different energy-reliant and energy-managing activities. In energy-reliant activities, energy is used by *energy-reliant artefacts*, such as radiators, stoves, and washing machines. Do such artefacts matter as regards which roles households take and play? In energy-managing activities, householders also use artefacts such as energy bills, timers, and the Internet (that is an energy-reliant artefact in itself). Do *energy-managing artefacts* matter for householders' roles in the energy system? To understand more about how householders' roles are being shaped, the first research question continues as follows:

RQ 1b. How do energy-reliant and energy-managing artefacts shape what roles householders consider and perform?

Comments to RQ 1b. 'Energy-reliant artefacts' are in research question 1b used to denote those energy-using artefacts that householders use in *energy-reliant activities*, that is to say mundane activities in which energy is just a necessary 'ingredient', such as preparing dinner or doing the laundry. Examples of energy-reliant artefacts are lamps and vehicles.

'Energy-managing artefacts' are in research question 1b used to denote those artefacts that householders use in *energy-managing activities*, that is to say activities in which energy is at the core, such as paying energy bills or installing solar panels. Examples of energy-managing artefacts are energy pricing schemes and solar panels. In my experience, there are normally fewer energy-managing artefacts than energy-reliant artefacts in a home.

1.3.3 Design of energy-reliant & energy-managing artefacts (RQ 2)

Energy systems are much more than just the energy they provide. Energy systems manifest themselves through the energy-reliant activities they make possible, through the energy-managing activities they necessitate, through the sensations they make possible, and through the physical and digital forms they take. All these manifestations can be, and sometimes are, designed to deliberately script their use (Lockton et al., 2010): how to use them, the experiences of using them, and the meanings connected to them. Figure 1.3 shows an example of a radiator design concept that scripts an unusual way of experiencing and personalising thermal energy.

Figure 1.3. *An example of a radiator design that scripts unusual ways of experiencing and personalising thermal energy. Design by Anna Gotha, images available at http://www.annagotha.dk/modulo.html (reprinted with permission).*

Yet, even when not deliberately designed, manifestations of the energy system still carry scripts (Buchanan, 1985). The flat surface on top of a radiator will be used for drying socks or thawing buns, although not consciously designed with that intent.

This is not to say that artefacts decide how they will be used, there are numerous examples of how householders deliberately use things in very unexpected ways, but artefacts convey messages of what use they are intended for, and what their designers expect from users. When it comes to contributing to the development of socio-technical systems that support reduced negative energy-related environmental impact when they are embedded into everyday life, there are different ways in which designs can script forms of action.

Design as either backgrounding or foregrounding energy

In energy-reliant activities, design can *either* background or foreground energy use, as well as *either* showing or hiding the sources of energy and the energy supply method (e.g. electricity or district heating). In most radiators, for instance, no aspect of energy is made visible. In fact, even the radiators themselves are often hidden or anonymised as they are painted in neutral colours or kept behind radiator covers (Ketola, 2001). Few electric cords are seen on sketches and renderings of conceptual designs of new electricity-reliant artefacts. In a demonstration house (described in Zinko, 2006) district heating replaced electricity in modified white goods such as washing machines but when those washing machines were later produced commercially, they did not look different to other washing machines on the market; the energy supply method was hidden. In this way, design can be used to background energy in activities that energy makes possible.

As a response, design is sometimes used to instead foreground energy use, as in the example with the Power-Aware Cord, a cord which lights up as electricity flows through it (Backlund et al., 2006). Energy feedback systems relying on a more numeric form of feedback are another example of trying to foreground energy. Pierce and Paulos (2010) experimented with foregrounding the source of energy by tinting the light of a lamp depending on real-time use of local solar power, for instance. The Transparent Charging Station, see Figure 1.4, is transparent about how the available power is distributed between the cars that are charged. Attempts at foregrounding energy through feedback often result in new energy-managing activities (Selvefors, 2017), for instance an activity that involves taking an interest in energy. In this way, design can be used to foreground energy in energy-reliant activities and be part of creating new energy-managing activities.

Design as enabling energy conservation

An alternative to either backgrounding or foregrounding is to enable less energy-intensive ways of operating energy-reliant artefacts. By providing functions and settings that for instance “enable processes to be limited to what is needed in specific situations” or “make the use of less energy-intensive functions straightforward, the default option, or automatic” energy conservation can be facilitated. However, this must be done in a way that fits with the energy-reliant activity of which the artefact is part (Selvefors, 2017, pp. 84-85).


17:30
19:08

Figure 1.4 (left). *A charging station for electric vehicles that shows how the power that is available is distributed between the cars that are charged. Image by The Incredible Machine available at https://the-incredible-machine.com/chargingstation.html (reprinted with permission).*

One way of enabling energy-managing activates is to ask for people's participation and to facilitate by explaining when and how to do it. An example is Heat Pledge, a voluntary service by energy utility Helen Ltd. in Finland for residents who want to lower their heat use at peaks in consumption (Uusitalo, 2016). People who signed up for the service promised to (manually) reduce their heating when they received a phone message telling them that major peaks in consumption were expected (Uusitalo, 2016). More than 2800 signed up for the service (Helen Ltd., n.d.).

Design as a systemic approach to reduced energy use

Some designers call for more systemic approaches to reduced energy use (e.g. Strengers, 2014). In her thesis, Kuijer (2014) provided an example of such an approach. She explored the practice of personal washing and reconfigured that practice through design, a process resulting in a new way of washing and new concepts for doing this. Regarding car use, turning mobility into a transport mode-independent service is another example of a more systemic approach than, for instance, discouraging car use (Strömberg et al., 2018). In this way, design can be part of ways to more fundamentally change the preconditions for energy-reliant activities.

Design as scripting roles in energy systems

The design of energy-reliant and energy-managing artefacts can thus carry scripts for how to engage in both energy-reliant and energy-managing activities by backgrounding or foregrounding different aspects of energy, by enabling energy conservation and energy flexibility, and by more systemic approaches. It seems as though some of the artefacts, and thus some of the scripts, have been designed for some of the roles households could play in energy systems while other artefacts have been designed for other roles. Backgrounding, for instance, aligns with a passive consumer of energy while foregrounding aligns better with that of an energy-aware user. Strengers (2014) argues that most designs of both energy-reliant and energy-managing artefacts intended to be used in smart energy systems are designed for 'Resource Man'. Should we design for other roles too? Throndsen and Ryghaug (2015) found that while energy use has become more of a public issue (as opposed to a private one), indicating a less individualistic role for householders, there were few options for taking on this responsibility other than that of being an economically rational energy user who focuses on individual needs. How to design for the less individualistic roles as well? In striving for the prescriptive part of this thesis's aim, a question then emerges about how to design in ways that align with the roles householders could play in energy systems.

RQ 2. In view of the roles householders consider and play in energy systems, how could design of energy-reliant and energy-managing artefacts shape the potential for reduced negative environmental impact?

Comments to RQ 2. The 'energy systems' referred to in research question 2 are district heating systems, smart energy systems, and combinations of the two. The 'roles householders consider and play' refer to the roles found in research question 1a.

1.4 DEMARCATION

This thesis focuses on the roles householders play and could play in energy systems, as well as on the energy-reliant and energy-managing artefacts used to play those roles; in other words, a socio-technical sub-system of the wider energy system. The focus is also on energy use related to households, to the home and the private life that goes on in and around the home – but not to work. This focus does not mean that other parts of the energy system have been disregarded; information about other parts of the system is used, for instance information about the environmental impact of energy production, the possibilities provided by different storage and distribution techniques, and the opportunities that ICT can provide. Furthermore, suggestions for other parts of the system are proposed, for instance about cooperation between different actors in the energy system. Nevertheless, households are the sub-system that is explored through research questions 1a and 1b, and the attempts to shape potential for less negative environmental impact, addressed through research question 2, also concern energy-reliant and energy-managing artefacts intended for households.

1.5 SUMMARY

Reducing energy use and increasing the share of renewable energy sources are important to mitigate climate change. However, to achieve this, low-carbon innovations within the energy sector need to first be developed and then adopted and appropriated by end-users. This thesis therefore aims, in short, to increase knowledge about and contribute to development of socio-technical systems that, when they are embedded into everyday life, support reduced negative energy-related environmental impact. To understand more about how to support such a reduction, the first research question addresses what role households could play in energy systems (RQ 1a) as well as how energy-reliant and energy-managing artefacts shape those roles (RQ 1b). Furthermore, in order to contribute to development of socio-technical systems that support the aforementioned reductions, research question 2 concerns how design of energy-reliant and energy-managing artefacts could shape the potential for reduced negative environmental impact. This thesis is thus focused on households and the artefacts used in households, but that does not mean that other parts of the energy system have been disregarded, or that no suggestions for other parts of the system are proposed.


Den här grejen ger mig:
värme varmvatten
Jag tror att den här grejen använder mycket energi.
Kommentarer?

här grejen ger mig:
värme varmvatten
Jag tror att den här grejen använder mycket energi.
Kommentarer?

Photo from Study A.

2 FRAME OF REFERENCE

The previous chapter highlighted the need to increase understanding of what roles households could play in energy systems (cf. RQ 1a), the importance of energy-reliant and energy-managing artefacts for those roles (cf. RQ 1b), and acknowledgement that those roles are expressed in energy-reliant activities and energy-managing activities – materialised ways of doing in everyday life. In the quest for an energy system with less negative environmental impact, these activities will also have to undergo change. This chapter therefore describes useful theories for understanding materiality, doing, and change in the everyday. However, such "social theories do not lead directly to prescription for action" (Shove et al., 2012, p. 126). In order to also obtain a prescription for action – which in this thesis means a prescription for the design of energy-reliant and energy-managing artefacts – the second part of this chapter focuses on theories that describe how design could shape potential for energy systems with less negative impact on the environment (in line with RQ 2).

2.1 MATERIALITY, DOING & CHANGE IN THE EVERYDAY

As argued in the introduction, we need to either move away from simplistic models of technological and social aspects of change which either assume that technology will 'fix' environmental problems in ways so that behaviour change will only need to play a limited role, or from a technosceptic point of view which instead emphasises the role of behaviours and distrusts the technological development (Brand & Fischer, 2013). Another closely related way of explaining the divide is a split between either structure or agency as a main explanatory factor for change (Brand & Fischer, 2013). As an alternative, Brand and Fischer (2013) suggest that we use theories which recognise technology and the social as integrated; as a socio-technical web in which technology and the social should be understood as co-evolutionary. To understand the roles householders could play in energy systems (cf. RQ 1a), it is therefore necessary to have theories that explain these roles as part of a socio-technical context and changes in roles as a co-evolutionary process including both technological and social aspects. Furthermore, to understand how energy-reliant and energy-managing artefacts shape the roles that householders consider and perform (cf. RQ 1b), theories that shed light on artefacts in socio-technical webs are needed.

The 'practice turn' in social science has brought attention to theories that could cross the divide between the technophilic and the technosceptic without prioritising either agency or structure and at the same time could emphasise the critical role of materiality (Kuutti & Bannon, 2014; Shove et al., 2012). In this chapter, two such theories will be described: social practice theory and activity theory. These two theories were chosen as they have both been used:

- in research related to different aspects of sustainability in everyday life (e.g. Selvefors et al., 2015; Shove et al., 2008; Strömberg, 2015);
- for understanding both stability and change in doings (Gram-Hanssen, 2011; Strömberg, 2015);
- for understanding the role of materiality in terms of artefacts (e.g. Hagensby Jensen et al., 2018; Selvefors et al., 2018); and
- for designing artefacts with a research through design methodology (e.g. Boon et al., 2018; Kuijer, 2014).

2.1.1 Social practice theory

In various areas of research into sustainability, including that of energy in everyday life, social practice theory is used (Wilhite, 2013) to understand both stability and change in everyday life (Gram-Hanssen, 2011; Shove et al., 2012). "Practice theories foreground what people actually do in ordinary life"(Spaargaren et al., 2016, p. 9). Everyday life is understood as a web of practices, where a practice is "a routinized type of behavior which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge" (Reckwitz, 2002b, p. 249). Practices are social because they are shared by many people and because they focus on 'social' phenomena such as shared understandings, meanings, and social norms (Shove et al., 2012)

Practices-as-entities & practices-as-performances

Practices are shared by many people in the sense that they exist as recognisable combinations of elements, as *entities*, that can be spoken about and used as sets of resources or a 'pattern' when performing a practice (Shove et al., 2012). It can thus be said that practices exist as entities, *practice-as-entity.* Yet, practices are also *enacted*; they exist as performances, as *practice-as-performance*. The performance of practices depends on the patterns and resources that the practice-as-entity constitute. Even so, the practice-as-entity depends on the performance for its survival: "It is only through successive moments of performance that the interdependencies between elements which constitute the practice as entity are sustained over time" (Shove et al., 2012, p. 18). One single performance of a practice is thus merely one of many varieties of manifestation of that practice-as-entity (Kuijer, 2014). Together, all the elements and links in all the performances of one practice constitute that practice as an entity, see Figure 2.1.

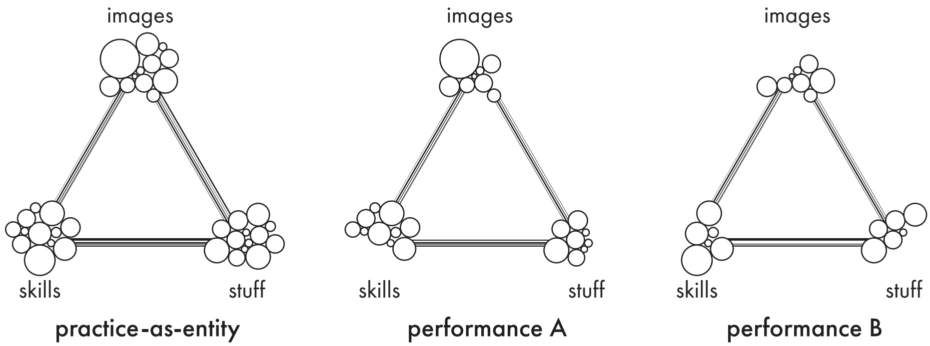


Figure 2.1. *A practice-as-entity consists of elements – images, skills, and stuff – and links. Elements and links in all the performances of a practice (A and B in this figure) together constitute the practice-as-entity. (Figure adapted from Kuijer, 2014, p. 53.)*

Elements of practice

Practices, both as entities and as performances, are configurations of elements that 'work', and they work because the elements are linked through the process of doing (Shove et al., 2012). Reckwitz' (2002b) rather extensive list of elements has for practical reasons been grouped in different ways, where the currently most used grouping is into the three groups *materials*, *competences*, and *meanings* (by Shove et al., 2012), sometimes rephrased as *stuff*, *skills*, and *images*, respectively (Kuijer, 2014). Material elements are objects, technologies, infrastructures, (manufactured and non-manufactured) materials of which the aforementioned are made, and including also people's bodies (Shove et al., 2012). Material elements are socially shared as similar things are available to many, though not always equally accessible to all (Kuijer, 2014). Competences are learned skills, know-how, and techniques (Shove et al., 2012) as well as knowledge about what is good, normal, acceptable, and (in-)appropriate (Kuijer, 2014). Meanings include ideas, aspirations, as well as social and symbolic significance of participation in the practice (Shove et al., 2012). A practice's meaning is the element in a practice that changes the most easily (Shove et al., 2012). In this, the 'Shovean' tradition, meaning is treated "as an element of practice, not something that stands outside or that figures as a motivating or driving force" (Shove et al., 2012, p. 31). There are other versions of social practice theory that describe practices as having motivating forces or purpose (cf. teleoaffective structures in Schatzki, 1996). Gram-Hanssen (2011) builds on these versions as she groups the elements of practice into (1) know-how and embodied habits, (2) institutionalised knowledge and explicit rules, (3) engagements, and (4) technologies. The third element, engagements, is explained as follows: “People want something or mean something with what they say and do, and this is also where reflectivity comes into practices” (Gram-Hanssen, 2011, p. 75).

Individuals as carriers of practices

The two different groupings of elements in social practice theory give rise to the question of the role individuals play in practices and in practice theory. Social practice theory is not primarily concerned with what people as individuals do, but with the shared social practices that individuals enact. The role of the individual is described slightly differently within the different strands of social practice theory. Shove et al. (2012) build on Reckwitz’ (2002b) description of individuals as carriers of a practice and do not consider individuals to ‘have’ any of the elements of a practice as the elements reside in the practice; an individual “is not only a carrier of patterns of bodily behaviour, but also of certain routinized ways of understanding, knowing how and desiring. These conventionalized ‘mental’ activities of understanding, knowing how and desiring are necessary elements and qualities of a practice in which the single individual participates, not qualities of the individual” (Reckwitz, 2002b, p. 250). Gram-Hanssen (2011), on the other hand, points out that individuals have agency over their practices-as-performances: “People can actually consciously decide to change their routines, if they are engaged to do so” (Gram-Hanssen, 2011, p. 75). Although emphasising that our individual performances are “formed and sustained by collectively shared elements” (Gram-Hanssen, 2011, p. 75). Seyfang et al. (2010) describe this multifaceted understanding of individuals:

> “Individuals (…) are no longer either passive dupes beholden to broader social structures, or free and sovereign agents revealing their preferences through market decisions, but instead become knowledgeable and skilled ‘carriers’ of practice who at once follow the rules, norms and regulations that hold practice together, but also, through their active and always localised performance of practices, improvise and creatively reproduce and transform them.” (Seyfang et al., 2010, p. 8)

Changes in practices – seeking to engender change

Practices change when links between elements are made and broken; they “change when new elements are introduced or when existing elements are combined in new ways” (Shove et al., 2012, p. 111), see Figure 2.2. Kuijer (2014) points out that ‘new’ does not by default mean ‘new to the world’, but rather new to that practice-as-entity and suggests using the term ‘unfamiliar’ elements. She further describes that unfamiliar elements can be materials, competences, and meanings. However, the ‘Shovean’ “streamlined approach” to practice theory has little to say about where these unfamiliar elements originate as they are described as “somehow ‘out there’ in the world, waiting to be linked together” (Shove et al., 2012, p. 31).

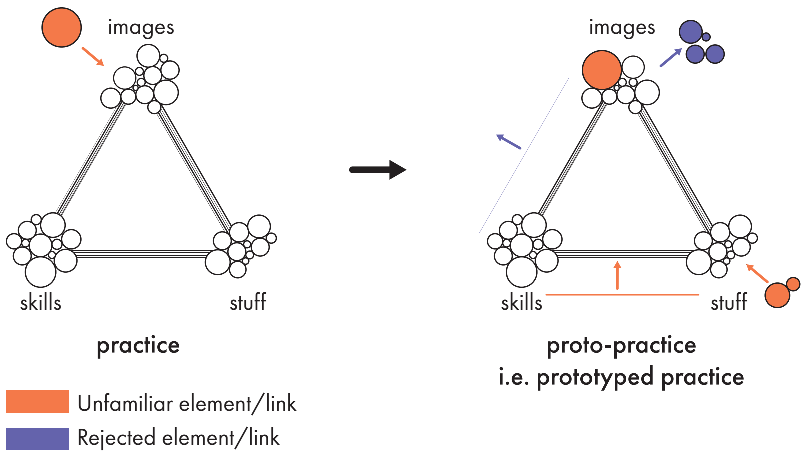


Figure 2.2. *A practice is reconfigured when an unfamiliar element is integrated into the performance (figure adapted from Kuijer, 2014, p. 76).*

If practices change when unfamiliar elements are introduced, then all technical innovations (or in fact all new elements) result in innovation in practice (Shove et al., 2012), as long as the innovation comes into use. From this argumentation follows that although the people involved in developing elements of some kind, for instance material elements, are in control of that element, they are rarely in control of how the elements are integrated in a practice (Shove et al., 2012). In addition, the very introduction of unfamiliar elements in a practice transforms the practice as materials, meanings, and competences shape each other. Reckwitz (2002a) explains that when people have developed practical understanding and "certain forms of know-how regarding certain things these things 'materalize' or 'incorporate' this knowledge" (Reckwitz, 2002a, p. 212), but only *within* the practice; beyond the practice things do not incorporate anything.

All in all, when unfamiliar materials are integrated in a practice, they transform the practice, and at the same time the practice transforms the materials. Consequently, material artefacts can never, in a strict causal way, shape a practice (Reckwitz, 2002a). Yet, "artefacts do not allow any arbitrary practical use and understanding, they are not suitable for arbitrary practices" (Reckwitz, 2002a, p. 212), or in other words, material artefacts "'script' and structure the manner in which they are used" (Shove et al., 2012, p. 36), in the sense that they make some courses of action possible and prevent others. As Akrich (1992, p. 12) puts it, technical objects "…define a framework of action together with the actors and the space in which they are supposed to act".

Despite acknowledging this inherent potential of material things to allow and prevent certain courses of action, social practice theory "has very little to say about how to deliberately 'design' change in a desirable direction" (Kuijer, 2014, p. 81). Fortunately, as Kuijer (2014) points out, theories for design have more to say on that topic.

Links between elements in performances of practices are being made and broken all the time as people, in their everyday lives, innovate and change their practices-as-performances (Shove et al., 2012). It is the overall accumulation of what appears as incremental innovation and minor adjustments in performance that over time results in changes also in the practice-as-entity (as summarised by Jensen, 2017). Nonetheless, carriers of practices are not necessarily aware that they are innovating and adjusting their practices-as-performance. For instance, few people consider themselves to be part of transforming their way of showering, let alone transforming showering. However, viewed in totality, the practice of showering is changing (Shove et al., 2012).

2.1.2 Activity theory

Activity theory is, just like social practice theory, a cultural theory of doing that locates social aspects of life in doings, but the description of 'doing' differs. Instead of taking practices as units of analysis, activity theory argues that an activity is the smallest meaningful unit to study. Activity theory aims to understand individuals as well as the social groups they compose in their everyday lives through analysis of their activities (Kaptelinin & Nardi, 2006).

An activity can be understood as a purposeful interaction of a subject (e.g. a person) with the world (Kaptelinin & Nardi, 2006; Leont'ev, 1978). In activity theory, people (subjects) are thus not seen as interacting with a product's interface, for instance; instead people interact with the world "through the interface" (Bødker, 1987; Kaptelinin & Nardi, 2006). Activities are purposeful interactions in the sense that they are always directed towards an object of the subject's needs (Leont'ev, 1978, pp. 52, 62). The object distinguishes one activity from another and the object is an activity's *motive* (Leont'ev, 1978, p. 62). As explained by Kaptelinin and Nardi (2006), it is only in an activity that the properties of a subject and an object exist; the properties exist as they are being enacted in a unity of consciousness and activity. Thus, the subject and the object cannot be understood separately, but only as part of an activity. Activities are, therefore, the smallest meaningful unit of analysis (Kaptelinin & Nardi, 2006).

'Objectified' needs as true motives of activities

In activity theory there is no list of specified needs that people have (Ilmonen, 1981), as opposed to Maslow (1943) for instance. Instead, needs manifest themselves in a feeling of dissatisfaction or discomfort and a will to rid oneself of that feeling (Ilmonen, 1981). When a person identifies an object that could satisfy the need, the need becomes 'objectified' and an activity directed towards that object emerges (Kaptelinin & Nardi, 2006); a need results in an activity only if the need is reified or made concrete in an object corresponding to the need (Ilmonen, 1981). (Note also that an object can be another person – someone that the subject directs its activity towards.) In an activity, the object motivates a person's activity (Kaptelinin & Nardi, 2006), and the object is therefore an activity's true motive (Leont'ev, 1978), although the person may not be immediately aware of the motives (Kaptelinin & Nardi, 2006). Engeström (2000) expanded the activity to also include the outcome of the activity, which can be either a transformation of the object or something else that the activity is intended to 'result' in. Based on Engeström (2001) Kain and Wardle (2005, p. 120) describe the object as "problem space", the outcome as "desired goals of the activity", and the motive as overarching the object and the outcome and thus as providing "purposes, reasons for the activity", see Figure 2.3.

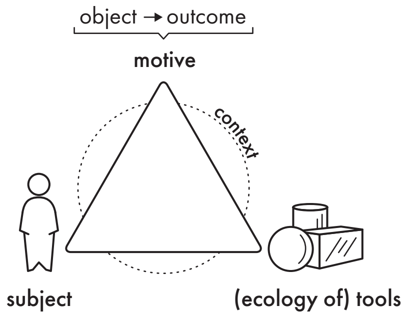


Figure 2.3. *The basic components of an activity (figure adapted from Engeström, 2001; Kain & Wardle, 2005; Selvefors, 2017).*

An activity can have several motives, related to different needs. However, if these motives cannot be pursued at the same time the activity will lack direction until one object unifies the set of motives (Kaptelinin & Nardi, 2006). To sum up, an object corresponding to a person's need becomes the motive, or unifies several motives, of an activity aimed at satisfying that need (Ilmonen, 1981; Kaptelinin & Nardi, 2006; Strömberg, 2015).

Agency in activity theory

In activity theory, it is *subjects* that interact with the world. "Subjects live in the world and they have needs that can be met only by being and acting in the world" (Kaptelinin & Nardi, 2006, p. 32). The subject of an activity manifests an agency of a character that an object does not have: "the ability and the need to act" (Kaptelinin & Nardi, 2006, p. 33). Non-living things lack *internal* needs to act, and subsequently to survive and can therefore not be the subject in an activity (Kaptelinin & Nardi, 2006).

Activities as hierarchical

Activities manifest in *actions*, or chains of action, (Leont'ev, 1978) and *operations* that together may eventually result in the desired outcome (Kaptelinin & Nardi, 2006), see Figure 2.4 and Figure 2.5. The actions are also directed towards objects, but these objects are not the motive of the entire activity and to distinguish them, these objects are called *goals* (Kaptelinin & Nardi, 2006). The goals are conscious; we are typically aware of what goals we want to fulfil (Kaptelinin & Nardi, 2006). Actions can be broken down into *operations*, routine-based doings that we typically are not aware of performing. These operations are directed towards the *conditions* under which the goal is being fulfilled (Kaptelinin & Nardi, 2006). Some skills start as conscious actions and, as we get more experienced, turn into automatised routine operations. Likewise, if the conditions change, what was a set of unconscious operations may have to turn into a set of conscious actions. Thus, while the object of an activity remains the same, goals, actions and operations may change as the conditions change (Kaptelinin & Nardi, 2006).

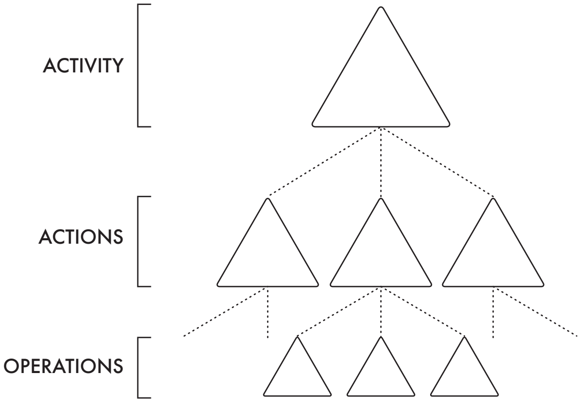


Figure 2.4. *An activity's hierarchical structure (figure adapted from Selvefors, 2017).*

Mediation

An activity always contains artefacts of various kinds, often referred to as *tools* (Kaptelinin & Nardi, 2006; Kuutti, 1996) (or as *instruments* (Engeström, 2000)). Tools can be both internal (such as a plan) and external, the latter being both material and non-material: anything from language, laws, and forms of organising work to instruments, machines, and energy systems (Kuutti, 1996). In a design context, what is of most interest are material artefacts. In activities, people act *with* tools (Kaptelinin & Nardi, 2006); tools *mediate* people's interactions with the world. The object of an activity is thus not acted upon 'as such' but within the boundaries set by the tool; a tool that is both *enabling* and *limiting* (Kuutti, 1996). The structural properties of the tool, such as its shape and material, reflect the experience of other people who have tried to reach similar goals and invented or modified the tool's predecessors (Kaptelinin & Nardi, 2006). As summarised by Kuutti (1996, p. 24), the tool "empowers the subject in the transformation process with the historically collected experience and skill 'crystallized' to it but it also restricts the interaction to be from the perspective of that particular tool". As tools have been created and transformed as the activity they mediate has developed, they should never be treated as something 'given' (Kuutti, 1996). Although here conceptualised as *one* tool, a tool can be an artefact ecology, that is to say a combination of artefacts (Bødker & Klokmose, 2011)

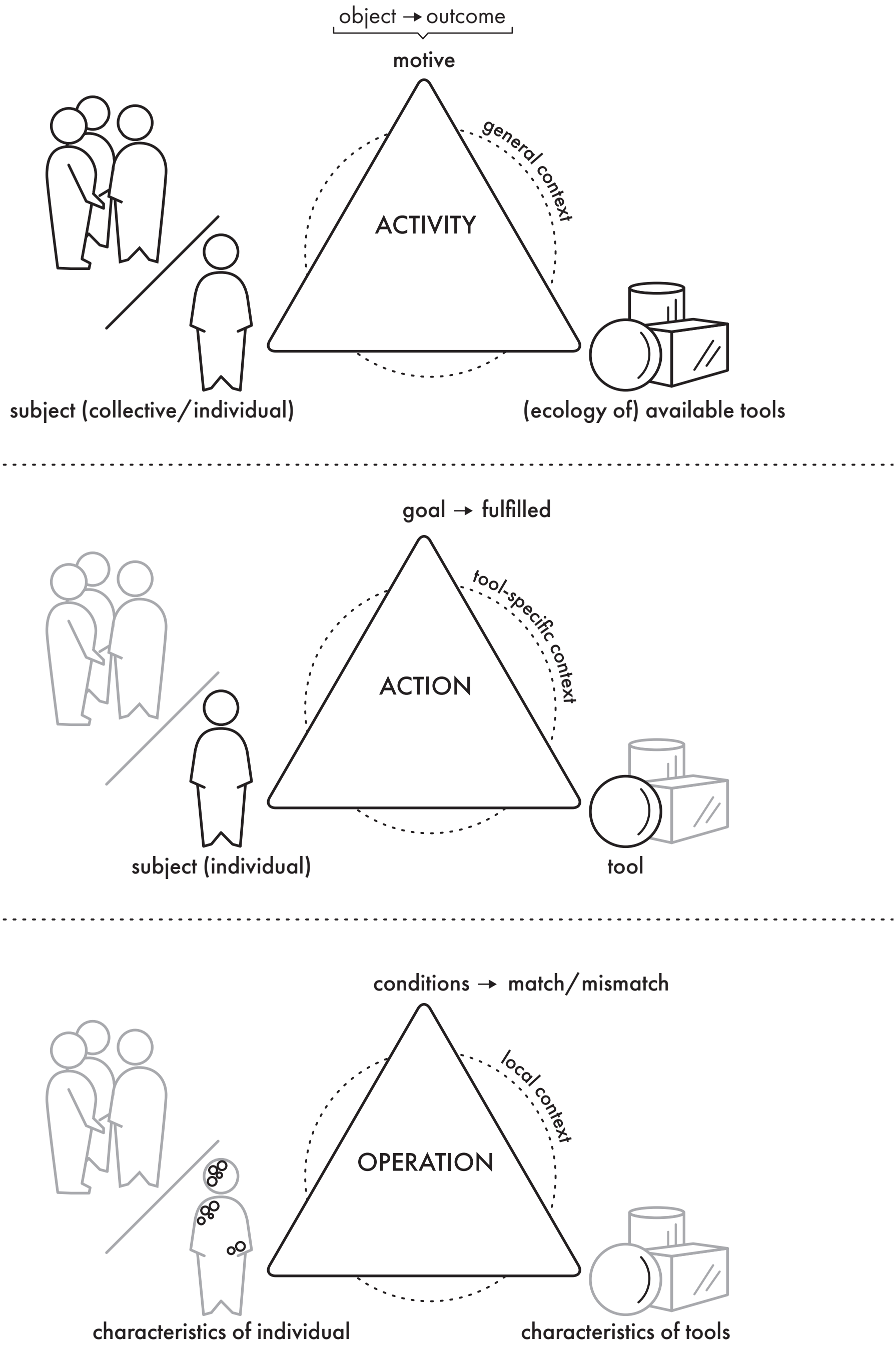


Figure 2.5. *An activity, an action, and an operation (figure adapted from Engeström, 2001; Kain & Wardle, 2005; Selvefors, 2017).*

or, at the level of activity, all the available tools that a person could choose to make use of in the activity (Karlsson, 1996).

A tool as a mediator in activities works well if it allows someone to focus on the object of the activity, and not cause *breakdowns* that draw attention to the tool as such (Bødker & Klokmose, 2011). Breakdowns occur due to *mismatches* between the different components of an activity (Bødker & Klokmose, 2011). Bødker and Klokmose (2011) recognise two mismatches: (i) between what someone wants (object) and what it is possible to do with the given artefact (tool), an object-tool mismatch, and (ii) between the preferences or preconditions of someone (subject) and the characteristics of the artefact in terms of how it is handled (tool), a subject-tool mismatch. Selvefors (2017) and Babapour (2019) recognise a third mismatch: between someone (subject) and the motive of the activity (object) meaning that someone does not want to engage in an activity (anymore) – a subject-object mismatch. In addition, Selvefors (2017) describes *fits* between component of an activity as the opposite of mismatches: fits are when two components support each other. Babapour (2019) uses the term *matches* to describe fits and that term will also be used in this thesis. See Figure 2.6 for an overview of how matches and mismatches were defined in user studies by Babapour (2019).

employee – AFO

Matches/mismatches between the informants' preferences and preconditions and the AFO: fulfilment or nonfulfilment of the informants' needs, desires, or preferences for comfort, enjoyment and wellbeing.

AFO – activity

Matches/mismatches between the AFOs and the employees' activities and actions: ways in which the AFOs were perceived to support or impede employees' activities.

employee – activity

Matches/mismatches between the employees and the motives for their activities: when the employees stopped wanting to engage in or changed their activities when relocating to an AFO.

Figure 2.6. *Three types of matches/mismatches identified in studies of employers' dis/satisfaction with activity-based flexible offices (figure adapted from Babapour, 2019, p. 26).*

Change & development

Change and development are important concepts in activity theory. In fact, the activities of today's everyday life are seen as a result of the cultural-historical context in which they have been shaped and continually are shaped (Kaptelinin & Nardi, 2006). Contradictions in and between activities become generative forces of development as any solution intended to resolve the contradiction also gives rise to new contradiction, in a dialectical manner (Kaptelinin, 2013; Selvefors, 2017). As described earlier, tools carry with them the experiences of other people and their collective attempts to attain similar goals. As tools develop the activity they enable also develops and gradually shapes both the goals and motives of people involved in activities (Bødker & Klokmose, 2011). Through activities, both the subject and the object thus develop (Kaptelinin & Nardi, 2006) and in this dialectic process, it is not possible to predict the future.

2.1.3 Position of research in relation to social practice theory & activity theory

Both social practice theory and activity theory describe socio-technical systems of doing, although in terms of practices or activity respectively. Both theories could therefore be useful for investigating what role householders in their everyday lives could play in energy systems and they have previously been used in similar undertakings. Social practice theory has been widely used (e.g. Goulden et al., 2014; Hagensby Jensen et al., 2018; Katzeff & Wangel, 2015; Katzeff, Wessman, et al., 2017; Naus, 2017; Shove, 2003; Strengers, 2012). Activity theory has been less used, although Selvefors and colleagues have used the theory both to understand energy use (Selvefors, 2017; Selvefors et al., 2015) and to suggest ways of designing (Selvefors et al., 2018). Activity theory has also been used to explore activities related to other facets of modern society with major environmental implications: the transport system (Rhodin, 2001; Strömberg, 2015), clothing (Rhodin, 2001), and consumption (Rexfelt & Hiort af Ornäs, 2009). Reviews of the two theories show that there are differences between the theories, and these differences have in my research made them useful for different purposes.

Individual, collective & shared socio-technical systems of doings

Activity theory takes *one* subject's activity as the starting point, although this one subject may be either an individual or a collective. However, the subject in an activity is not seen as developing the objects that motivate their activities 'on their own'. These objects are specific to the society to which the subject belongs and are appropriated by the subject through relations with others (Roth, 2014). Thus, although one subject's activity is taken as the starting point, that activity is directed towards a generalised, collective, and shared societal need. As the tools – simultaneously enabling and limiting – that are used to mediate a subject's interactions with the world reflect the experiences of other people facing similar situations (Kaptelinin & Nardi, 2006; Kuutti, 1996) these tools also carry a collective dimension. Thus, although activity theory takes one subject's activity as the starting point, it anchors the activity in collective/shared ways of doing (Bødker & Klokmose, 2011). However, from the perspective of reduced environmental impact, what matters most is what a lot of people do and not what one person/collective does even if it is understood in relation to others' ways of doing. In social practice theory, the shared system of doings, that is to say the practice-as-entity, is the starting point for analysis. The individual's way of doing, the practice-as-performance, is studied as a way of grasping the practice-as-entity (cf. Kuijer, 2014). Social practice theory thus seems more fit for understanding a specific socio-technical system of doings in relation to the wider setting of (various aspects of) sustainability in society. In my work, social practice theory has been used as an overarching framework for the implications of our shared practices on the potential for a more sustainable energy system on a societal level. Social practice theory has also been used as a means of interpreting the work of others who have used this approach (for instance Strengers, 2013). However, in my empirical studies of individuals' systems of doings I have used activity theory, for reasons that are elaborated in the two following sections.

Change in individual socio-technical systems of doings

Activities are purposeful interactions with the world. They are purposeful in the sense that they are directed towards an object that motivates the activity. This object-oriented aspect provides an explanatory framework as to *why* and *how* individual activities change. In these activities, tools are used as mediators, and different tools mediate the activity in different ways – in more or less satisfactory ways. Tools that seem to better mediate the activity are therefore used, and these tools, in turn, change the object of the activity, and as a result, another tool might be preferred in the activity, and so on. In this way changes in activities can be described and understood, although not predicted. Social practice theory provides an explanatory framework for *how* practices-as-entities change; they change as elements and links between elements in practises-as-performances are made and broken. However, social practice theory does not provide an established vocabulary or framework for analysing *why* innovations and adjustments in practices-as-performances occur. Activity theory thus seems to be more suitable for analysing how and why individual performances of socio-technical systems of doings change. In my work, I have therefore used activity theory to inform the set-up and analysis of research studies regarding individual current and future socio-technical systems of doings. The roles that householders could play in energy systems (cf. RQ 1a, 1b, and 2) could therefore also be understood in terms of activity theory. Roles are thus understood as (i) *which* (mostly ecologies of) energy-reliant and energy-managing activities householders consider and perform, (ii) *how* these activities are carried out, and (iii) *what outcomes* with direct and indirect relevance for the energy system the householders intend for their activities. Energy-reliant and energy-managing artefacts (cf. RQ 1b and 2) are understood as mediating *tools* in activities that have an outcome with relevance for the energy system.

Designed artefacts in social practice theory & activity theory

Designed artefacts are present in both (the 'Shovean' version of) social practice theory and activity theory, in the form of material elements and tools respectively. Nevertheless, although the characteristics of things are described as important in social practice theory, it does not deal with *how* the characteristics of designed artefacts show potential in practices-as-performances. For instance, designed artefacts are described as 'scripting performances', but it is not explained *how* designed artefacts script performances. Having said that, when prototyping and designing, one must also define the characteristics, and the characteristics of a design can impact the experience of the whole (Monö, 1997). The hierarchical structure of activity theory that separates an activity into conscious actions and unconscious operations provides a basis for understanding how designed artefacts – the artefacts as a whole, their motive-related aspects, and their characteristics – enable and limit an activity in different ways and on different levels (Bødker & Klokmose, 2011). In my work, activity theory has therefore been used for user studies intended to inform design work as well as to understand how the design of energy-reliant and energy-managing artefacts can shape potential for reduced negative energy-related environmental impact (cf. RQ 2).

2.2 DESIGN FOR A MORE SUSTAINABLE EVERYDAY

Design theory and practice have recognised and engaged sporadically with various aspects of sustainability issues since the mid-twentieth century, in a more focused way since the 1970s, and since the 1990s as a field of research (see e.g. Ceschin & Gaziulusoy, 2016; Thorpe, 2010). In the 1990s, design efforts were made to improve existing or develop new products (Ceschin & Gaziulusoy, 2016) that did not require substantial change in lifestyles, such as the increased use of recycled materials (Thorpe, 2010). The results of such efforts are what Kuijer (2014) calls resource-efficient products. Design approaches that took the whole product life-cycle into consideration were an important consequential milestone, as elaborated in *Ecodesign: A Promising Approach to Sustainable Production and Consumption* (Brezet & van Hemel, 1997), for instance. Although the term *sustainable consumption* existed since the policy document Agenda 21 from the Rio Earth Summit in 1992 (Jackson & Michaelis, 2003), it was not until the early 2000s that the design community started to explore lifestyle changes more explicitly (Ceschin & Gaziulusoy, 2016; Thorpe, 2010), with approaches such as Emotionally Durable Design (Chapman, 2009) and approaches that encourage what Kuijer (2014) calls resource-efficient interactions, examples include Design for Sustainable Behaviour (e.g. Lidman & Renström, 2011; Lilley, 2009) and Design with Intent (Lockton et al., 2010). Resource-efficient interactions are of particular interest when designing energy-reliant and energy-managing artefacts that shape potential for energy systems with less negative environmental impact (cf. RQ 2). Nevertheless, the focus on resource-efficient interactions and the interaction-oriented design approach that followed has been ctitiqued, as summarised by Kuijer (2014, pp. 16-20) in the following points.

- "Intended behaviour change may not be achieved". Interaction-oriented approaches often take rather specific use scenarios as starting-points. When actual use does not match these use scenarios the intended interaction may not be achieved.
- "Potential savings disappear in other changes". Even when a re-design

results in the intended interaction, the savings obtained are easily lost in larger trends of increasing consumption as interaction-oriented approaches usually focus on very limited problems and use far too simple metrics that do not do the complexity of sustainability justice.

- "Strong rhetoric of right and wrong behaviours". Interaction-oriented approaches often define what are 'good' and 'bad' behaviours and leave it to the designers – not to people themselves – to determine what is what.
- "Opportunities for larger scales of change are missed". In interaction-oriented approaches the responsibility for reducing resource use is delegated to individual users (and designers). However, changes on an individual level have a limited effect, given any interaction's cultural, social, and material environment (see also Scott et al., 2009).

As a response to these points of critique, a new area referred to as 'practice-oriented design' started to emerge and was later developed into an approach for sustainable design (Kuijer, 2014). Transition design (Irwin, 2015) and the Multilevel design model (Joore, 2010; Joore & Brezet, 2015) could be seen as other ways of responding to the criticism. Although promising, there are as yet few examples of how these responses can result in actual new design solutions, with Kuijer's (2014, 2017) work being one such successful example.

On the other hand, activity-oriented design was previously used in design and could also be useful in design for a more sustainable everyday life – since activity theory, just like social practice theory, goes beyond the level of interaction and acknowledges the critical role of materiality without prioritising either agency or structure (Kuutti & Bannon, 2014). In addition, as I have used activity theory to explore individuals' current and future socio-technical systems of doings and to inform design work, using activity theory in the design process too makes sense. However, when reviewing potential frameworks, none were found to cover the full range of artefact-related aspects: from how artefacts shape roles (cf. RQ 1b) to how artefacts could shape the potential for reduced negative environmental impact (cf. RQ 2). Many of the reviewed frameworks contain the detailing necessary for some aspects but not for the full range (Brezet et al., 2001; Muller, 2001; Roozenburg & Eekels, 1995; Warell, 2001). Only a few frameworks (Bødker & Klokmose, 2011; Hekkert & van Dijk, 2011) focused on use – which is central to this thesis's aim – yet none of those contained detailing regarding technical aspects, which is important for reduced negative environmental impact.

Therefore, in order to explore the possibilities of activity-oriented design in relation to design for everyday life with reduced negative environmental impact, I have, together with two colleagues, suggested a new framework. It highlights the possibilities of shaping potential for reduced negative environmental impact in relation to activity-oriented design, see the following Section 2.2.1 and appended Paper X.

2.2.1 Activity-oriented design for a more sustainable everyday

Activity-oriented design can be seen as a "…shift in attention compared to other forms of user-centred design, as the focus of the designer moves from the interaction between the user and the product, to the interaction between the user and the world, with help from the product" (Strömberg, 2015, p. 11). As a designer you should not design the interface, but design "through the interface" (Bødker, 1987a, title). In the appended Paper X, my colleagues and I present a framework that categorises the different aspects of artefacts that a designer can change to set the preconditions for the way people act with technology and consequently how that technology relates to (some aspects of) sustainability. We called this framework Layers of Design, as it describes artefacts as layered, see Figure 2.7. Drawing on these categories, a number of principles for (different forms of) sustainable design emerge, including principles for reduced negative environmental impact. These principles are introduced at the end of Section 2.2.1.

Layers of Design

When artefacts are understood as layered, a designer must first consider why artefacts are designed and which activity they mediate. The activity that the artefacts mediate is therefore considered to be the top layer in Layers of Design. At this level, design decisions determine the activities for which mediating tools will be made available in society. A thorough understanding of exactly which activities designers design for is essential so as to reduce negative environmental impact.

Layers of Design

what a designer can change to influence people's preconditions for acting with technology

- **Enabled activity** – *what activity to enable, i.e. what motives or needs to support*
  - **Artefact type(s)** – *what artefact type(s) to provide to support the motives*
    - **Operative functions**
      - **Operating concept** – *what technical approach to use*
      - **Practical functions** – *what functions to provide*
      - **Interactive functions** – *how to design the artefact to enable people to access the operative functions*
        - **Communicative functions**
          - **Semantic functions** – *how to use perceptual elements to convey meaning and facilitate interpretation*
          - **Syntactic functions** – *how to compose different perceptual elements to form a whole*

Figure 2.7. *Layers of Design – a categorisation of all artefact-related aspects that shape potential for reduced negative environmental impact. The categorisation thus shows what a designer can influence through design of artefacts.*

The next consideration for a designer is what *type* of artefacts to design: if the activity is to be thermally comfortable should the artefact type with which the activity is mediated be a radiator or a blanket? With regard to environmental sustainability, it is important to make artefact types available that enable the activity with little environmental impact. However, the types of artefacts made available might have to make different ways of doing possible to suit different people and their different webs of activities. The artefact type, existing or invented, to be designed constitutes the second layer of artefacts.

Thirdly, a designer must decide how the artefacts should operate: what the user should be able to do with the artefacts – referred to as practical functions – and through which technical approach the artefacts should deliver their main functions – referred to as the operating concept. Practical functions include all the things for which the artefacts are intended to be used, their main functions (e.g. give warmth), their necessary support functions (e.g. be possible to regulate), and their delighters (e.g. provide a drying rack for wet mittens). When designing practical functions, a designer deliberately sets the preconditions for use and, from a sustainability perspective, practical functions are important as they often facilitate the process of integrating artefacts into everyday life (Strömberg, 2015). Using different operating concepts (e.g. petrol car vs. electric car or induction cooktop vs. regular cooktop) provide different precondition for environmental impact and (very often) resource consumption, the latter in relation to type of resource (e.g. petrol vs. electricity), amount of resources (such as the efficiency of induction cooktops), and/or type of pollution. The operating concept also sets preconditions for use: an electric car can, for instance, be charged at home and the 'fuel' is paid for through the electricity bill but the car can currently not be driven as far as petrol cars can without a recharge.

The way users should access the functionality is the fourth layer of artefact design; this layer is called interactive functions. At this stage, a designer must decide on how the user should interact with and control artefacts; design decisions at this stage typically concern interaction sequences, interaction elements (such as buttons, displays, and sensors), and levels of user control (such as what to use automation for, if anything). The design of the interactive functions sets various preconditions, for instance how easy or convenient it is for people to use the artefacts and gain the full benefit of the artefacts' functions. From a sustainability perspective, the design of interactive function sets the preconditions for how they interact with artefacts with as little negative environmental impact as possible. An example of such a case is a wood-burning stove (Daae et al., 2016). For this particular wood-burning stove, users found it difficult to achieve a clean burn, but after a redesign of the levers that control the air intake users found it easier to optimise the burning (Daae et al., 2016); the design of the interactive functions (the levers) thus set the preconditions for reduced negative environmental impact (clean burn).

Finally, a designer can also influence artefacts' communicative functions, including both semantic and syntactic functions. Semantic functions describe artefacts' purpose and mode of operation; they express properties and encourage reactions; and they identify the artefact type: its origin, kinship, location, nature, or category (Monö, 1997). Syntactic functions comprise ordering of product form, and the composition of perceptual elements into a whole (cf. Muller, 2001). The communicative functions thus set preconditions for people's perceptions of artefacts, for instance understanding its purpose and how to use it, perceiving its properties, and experiences connected to interactions with it.

Design principles following from Layers of Design

When understanding artefacts as layered mediators of activities, as is done in Layers of Design, three principles emerge for design for reduced negative environmental impact in everyday life : design for alternative ways of doing, address aspects of sustainability *within* everyday activities, and connect all layers.

Design for alternative ways of doing. From activity theory follows that people use artefacts for *something*; artefacts are tools in activities directed towards objects. Artefacts can be designed to mediate the activity in different ways; for instance, as exemplified through Layers of Design, different preconditions in relation to reduced negative environmental impact. Creating enabling conditions means designing artefacts that mediate people's activities in ways with less negative environmental impact, or in other words, creating preconditions that enable people to satisfy their needs with less negative environmental impact (Selvefors, 2017). Here, the idea is not to influence what activity people engage in, but to address what artefact type is developed as well as what operative, interactive, and communicative functions to design.

Address aspects of sustainability within everyday activities. As touched upon in the introduction, there is a difference between energy-reliant activities and energy-managing activities. In Paper X, I and my colleagues argue that when it comes to (various aspects of) sustainability in everyday life the aspiration of satisfying everyday needs (i.e. focusing on energy-reliant activities) has generally been overshadowed by the ambition to enable new activities with the motive of (in different ways) 'being more sustainable' (such as many of the energy-managing activities): often short-lived activities that do not fundamentally influence the levels of sustainability of all the other activities that make up everyday life. The second principle is therefore to address issues regarding sustainability that lie within already existing everyday activities, by creating enabling conditions, and not to solely focus on mediating new activities with the motive of (in different ways) 'being more sustainable'.

Connect all layers. Seeing artefacts as layered mediators of activities highlights the necessity of addressing all the layers as design characteristics on all layers jointly set the preconditions for use (Selvefors, 2017). Addressing the artefacts as wholes as well as layered can be done by connecting all the layers; by systematically and iteratively working through all the layers of design. Moving upwards through the layers ensures effectiveness; the higher up, the greater the potential for reduced impact (Brezet et al., 2001). Working downwards through the layers helps create a coherent whole where the layers reinforce each other; communicative and interactive functions can for instance help reinforce the type of artefact (Strömberg, 2015). The lower layers can also be crucial for artefacts' integration into everyday life; for adoption and appropriation. Frustrating ways of interacting with artefacts can destroy the experience of using what could have been a great design, while well-designed communicative functions can turn mediocre practical functions into satisfying user experiences (see the example of frog dosing cup in Lidman & Renström, 2011).

2.2.2 Position of research in relation to Layers of Design

Layers of Design provides an overview of how artefacts can be understood and what designers can change through the artefacts they design. In my work, Layers of Design has been used as an explanatory framework to understand how artefacts shape what roles householders consider and perform (RQ 1b). Further, Layers of Design has been used to understand how artefacts could shape the potential for reduced negative environmental impact (RQ 2). In the design of energy-reliant and energy-managing artefacts, the three principles emerging from Layers of Design have been used. The second principle – address aspects of sustainability *within* everyday activities – has been used in all designs. The first principle – design for alternative ways of doing – has mainly been used in one design project. The third principle – connect all layers – was aspired for in all designs.

2.3 SUMMARY

Social practice theory and activity theory are two theories that could cross the divide between technical solutions to environmental problems and efforts to change behaviours and at the same time emphasise the critical role of materiality. These two theories were therefore considered to guide the work, mainly in regard to research questions 1a and 1b. Social practice theory was regarded as useful for its focus on shared ways of doing since when doings are shared by many, the environmental impact increases as more people are engaged in the practice. Activity theory was seen as useful for understanding individuals' doings, including how they change, as well as for how characteristics of artefacts shape both current and future doings.

No existing frameworks were regarded as useful for exploring how artefacts could shape potential for reduced negative environmental impact (cf. RQ 2). Together with colleagues, a framework called Layers of Design was therefore developed (see Paper X). In the framework, artefacts are regarded as structured in layers covering what artefact type they are, through operative and interactive functions, to what communicative functions they have. On all levels, designers set preconditions for reduced environmental impact when artefacts are used as tools in activities. Three principles for reduced negative environmental impact emerge from Layers of Design: *design for alternative ways of doing*, *address aspects of sustainability* ***within*** *everyday activities*, and finally *connect all layers*.


CHALMERS

Research in a living lab. Photo by HSB (reprinted with permission).

3 RESEARCH APPROACH

The previous chapter highlighted the existing theories that informed the research, in other words social practice theory and activity theory, as well as a framework that was developed in the course of this research, that is to say Layers of Design. This chapter highlights how the research was conducted: starting with my personal research drive and my worldview, continuing with the overall methodological approach, and finally describing the specific methods used in the research (cf. Creswell, 2014).

3.1 PERSONAL CONTEXT & THEORETICAL PERSPECTIVE

In order to provide insight into the personal values and the prior understandings that underpin my research, I will start by providing a short overview of my background and research interests (cf. Creswell, 2014). During my undergraduate education – studying Industrial Design Engineering at Chalmers University of Technology, Sweden and at Delft University of Technology, the Netherlands – I was introduced to a people-centred approach to product development and design. At Chalmers, I was introduced to a *socio-technical* understanding of artefacts through activity theory (as interpreted by e.g. Engelbrektsson, 2004). At Delft University of Technology, I adopted a broad, *technology-independent* understanding of what interaction is; that interaction is everything from how people understand and use artefacts, to how they experience them. During my undergraduate education I became increasingly aware of the disastrous consequences that technological development has on the planet, and thus on people. Designers and engineers have been, and are still, inevitably part of this technological development and therefore I feel that it is my responsibility to do what I can to support more sustainable development – this drive is the basic foundation for my research. From my perspective more sustainable development requires the emergence of environmental and social conditions that indefinitely support people's security, wellbeing, and health (based on the definition by McMichael et al., 2003 as understood by Thorpe, 2007). I consider the Sustainable Development Goals adopted by United Nations in 2015 (United Nations, n.d.-a) to be a good starting point for sustainable development as they reflect (at least some level of) agreement between nations and the people of the world. The research in this thesis is thus explicitly value-driven and action-oriented, preferring theory that can inform effective practice over theorising and philosophising (cf. Johnson & Onwuegbuzie, 2004).

3.1.1 Pragmatic, prescriptive & prospective research

The urgency of the routes towards sustainable development paves the way for a *pragmatic* understanding of the world and *pragmatic research*, that is to say an understanding that emphasises *doing what works* (cf. Johnson & Onwuegbuzie, 2004). Pragmatic research is explicitly oriented towards shared cultural values such as democracy, equality, or sustainable development (Johnson & Onwuegbuzie, 2004); if a pragmatic approach is described as 'doing what works' it is the underlying values that determine what 'work' means, in other words what the researcher wants to achieve.

Pragmatism recognises an external, physical reality as well as a socially constructed reality (Johnson & Onwuegbuzie, 2004), and that our "social constructions are bounded by the tolerance of an external reality" (Sayer explained by Johnson & Duberley, 2000, p. 157). Therefore, knowledge is viewed as based on the reality of the world we live in *and* as socially constructed (Johnson & Onwuegbuzie, 2004). Furthermore, "to have knowledge is the ability to anticipate the consequences of manipulating things in the world" (Johnson & Duberley, 2000, p. 159). In this thesis, 'knowledge' is therefore knowing what can be done to support more sustainable development, in other words representing *prescriptive* research into sustainability, although based on empirical findings resulting from research with a descriptive character. Theories are considered true to different degrees depending on how well they are currently working; 'currently' as both theories and knowledge are changing (cf. Johnson & Onwuegbuzie, 2004). A pragmatic approach endorses eclecticism and pluralism; it endorses the view that different – even conflicting – theories and perspectives can be useful, exemplified in this thesis for instance by using both social practice theory and activity theory.

The research questions in this thesis are future-oriented in the sense that they are concerned with how things *could* be: what roles householders *could* play and what artefacts *could* be designed. The research conducted is therefore not only prescriptive, i.e. concerned with how things *should* be, but also prospective, i.e. concerned with how things *could* be. Karlsson (1996) terms such a research approach towards studying the relation between householders and technology as *prospective prescriptive*. The research in this thesis is thus pragmatic, prescriptive, and prospective.

3.2 METHODOLOGICAL APPROACH

This thesis relies primarily on empirical research; it is this kind of research that has been used to respond to all the research questions. Non-empirical research based on reviewing literature was, however, used to develop the framework Layers of Design (presented in Chapter 2), see Table 3.1

Table 3.1. *Overview of the organisation of the research.*

RQ	Study	Type of study	Output
n.a. (framework development)	n.a.	Literature/theory-based conceptual research	Paper X
1a: what roles?	Study A	Descriptive study	Paper A
2: what artefacts?	Study B	Explorative design in Study B	Prototype kit
1b: shaping roles? 2: what artefacts?		Evaluation of prototype *in situ*	Paper B
1: what roles?	Study C	Descriptive study	Paper C
2: what artefacts?	Study D	Explorative design in Study D	Prototype Ero
1b: shaping roles? 2: what artefacts?		Evaluating prototype *in situ*	Paper D
1a: what roles?	n.a.	Cross-study analysis for RQ 1a	Chapter 4
1b: shaping roles?	n.a.	Cross-study analysis for RQ 1b	Section 5.2
2: what artefacts?	n.a.	Cross-study analysis for RQ 2	Section 5.1 and 5.3

The empirical research for this thesis has been organised into four main studies, Study A to Study D, and resulted in four appended publications, Paper A to Paper D, and two prototypes, see Table 3.1. In practice, Study A was separated into two parts and Study B and Study D included a design phase. The empirical studies were followed by three cross-study analyses that more precisely respond to the three research questions. The results of these analyses are presented in Chapters 4 and 5 in this thesis, as detailed in Table 3.1.

Study A and Study C were concerned with how things are; they were of a more descriptive character. The design phases in Study C and Study D were explorative, while the rest of Study C and Study D was evaluative. The four studies were essentially sequential and built on each other, see Figure 3.1. The methodological approach was informed by design research and inspired by an integrative research approach (also called a mixed methods approach). The way that design research and the integrative

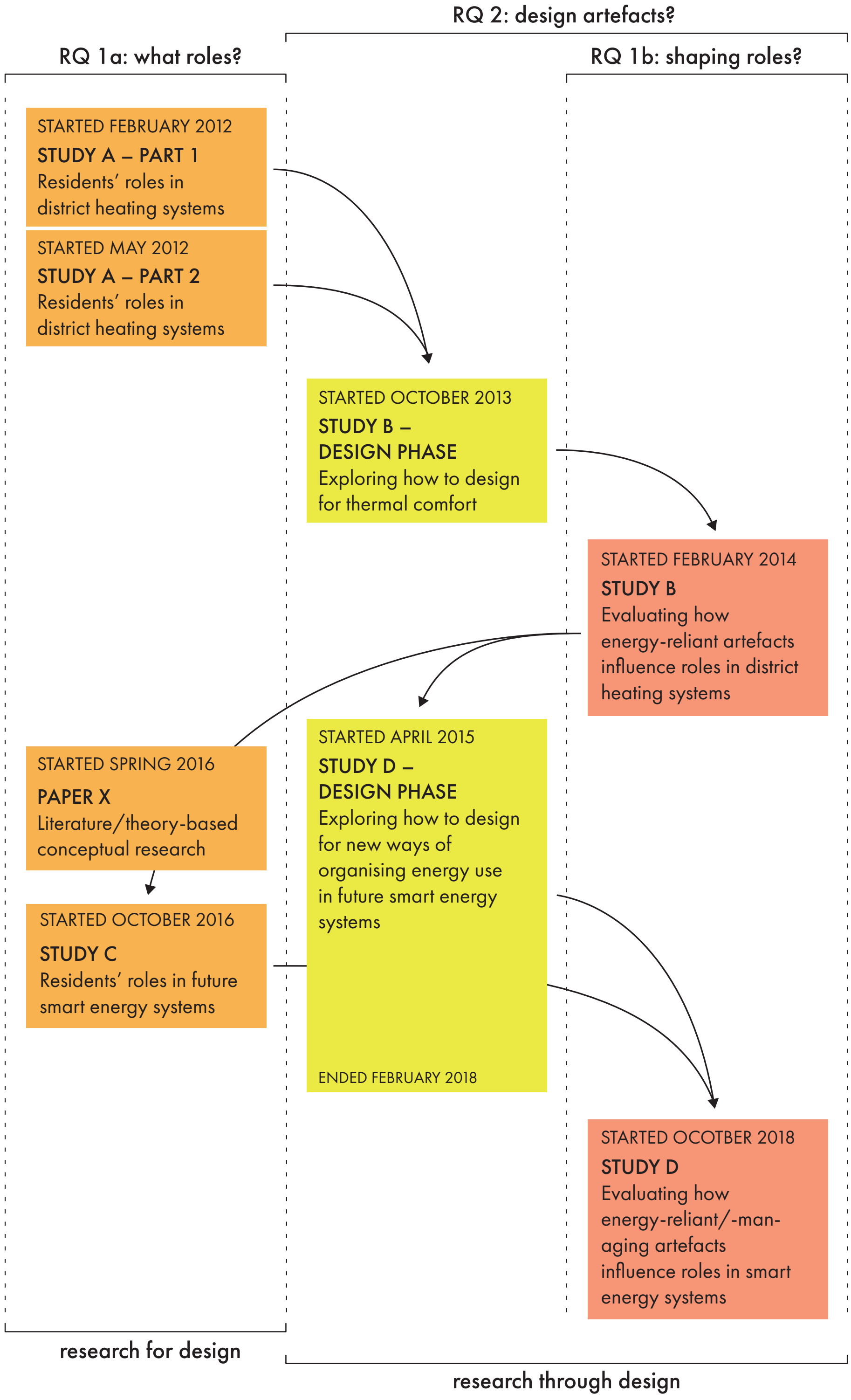

RQ 2: design artefacts?
RQ 1a: what roles?
RQ 1b: shaping roles?
STARTED FEBRUARY 2012
STUDY A – PART 1
Residents' roles in district heating systems
STARTED MAY 2012
STUDY A – PART 2
Residents' roles in district heating systems
STARTED OCTOBER 2013
STUDY B – DESIGN PHASE
Exploring how to design for thermal comfort
STARTED FEBRUARY 2014
STUDY B
Evaluating how energy-reliant artefacts influence roles in district heating systems
STARTED SPRING 2016
PAPER X
Literature/theory-based conceptual research
STARTED APRIL 2015
STUDY D – DESIGN PHASE
Exploring how to design for new ways of organising energy use in future smart energy systems
ENDED FEBRUARY 2018
STARTED OCTOBER 2016
STUDY C
Residents' roles in future smart energy systems
STARTED OCOTBER 2018
STUDY D
Evaluating how energy-reliant/-managing artefacts influence roles in smart energy systems
research for design
research through design

Figure 3.1 (left). *Overview of the empirical studies and their respective methodological approach in relation to research questions and time.*

approach was employed is elaborated on in the upcoming sections, followed by an introduction to the research context.

3.2.1 Design research

Design research can be described as research on design, research for design, and research through design (e.g. Forlizzi et al., 2009). Research on design is concerned with understanding the act of designing and related areas such as creativity (Forlizzi et al., 2009). It is the most recognised field of design research, but it is not used in this thesis. Instead, this thesis is concerned with research for design and research through design.

The term 'research for design' covers knowledge produced with the intention of being applied in design processes, such as conceptual frameworks, and design implications (Forlizzi et al., 2009); it is *knowledge for design*. Study A and Study C were both descriptive studies with the aim of creating knowledge for design. The non-empirical research for Paper X was also research for design as it aimed at creating a framework useful for designers.

'Research through design' can in short be described as "design activities that play a formative role in the generation of knowledge" (Stappers & Giaccardi, 2017, section 43.1.4), and could, according to Stappers and Giaccardi, be aimed just at making stimulus material. Typically however, research through design involves "developing a prototype (or artefact) that could be mistaken for a 'product' that plays a central role in the knowledge-generation process" (Stappers & Giaccardi, 2017, section 43.1.4). Zimmerman et al. (2007, p. 493, emphasis in original) describe research through design as a process that integrates knowledge from behavioural sciences and technical opportunities with findings from the field to create the *right* thing: "a product that transforms the world from its current state to a preferred state". The latter view thus emphasises the creation of the thing/prototype and the possibilities the thing/prototype have (i.e. transforming the world) while the former view emphasises the knowledge-generating capacities that the thing/prototype has. In this thesis, the latter view of research through design better explains the research undertaken in Study B and Study D; in the evaluations, the prototypes designed for Study B and Study D were used to generate knowledge, that is to say *knowledge from design*, see Figure 3.2.

The design and evaluation of the prototypes generated three forms of *knowledge from design*. First, the process of designing and prototyping them generated knowledge about *what can be designed* – this knowledge is demonstrated in the research prototype and is neither abstract nor generalisable (cf. Höök & Löwgren, 2012; Stappers & Giaccardi, 2017). Second, by designing and prototyping, insights about *how to design* in a given context were also generated – knowledge in the shape of preliminary

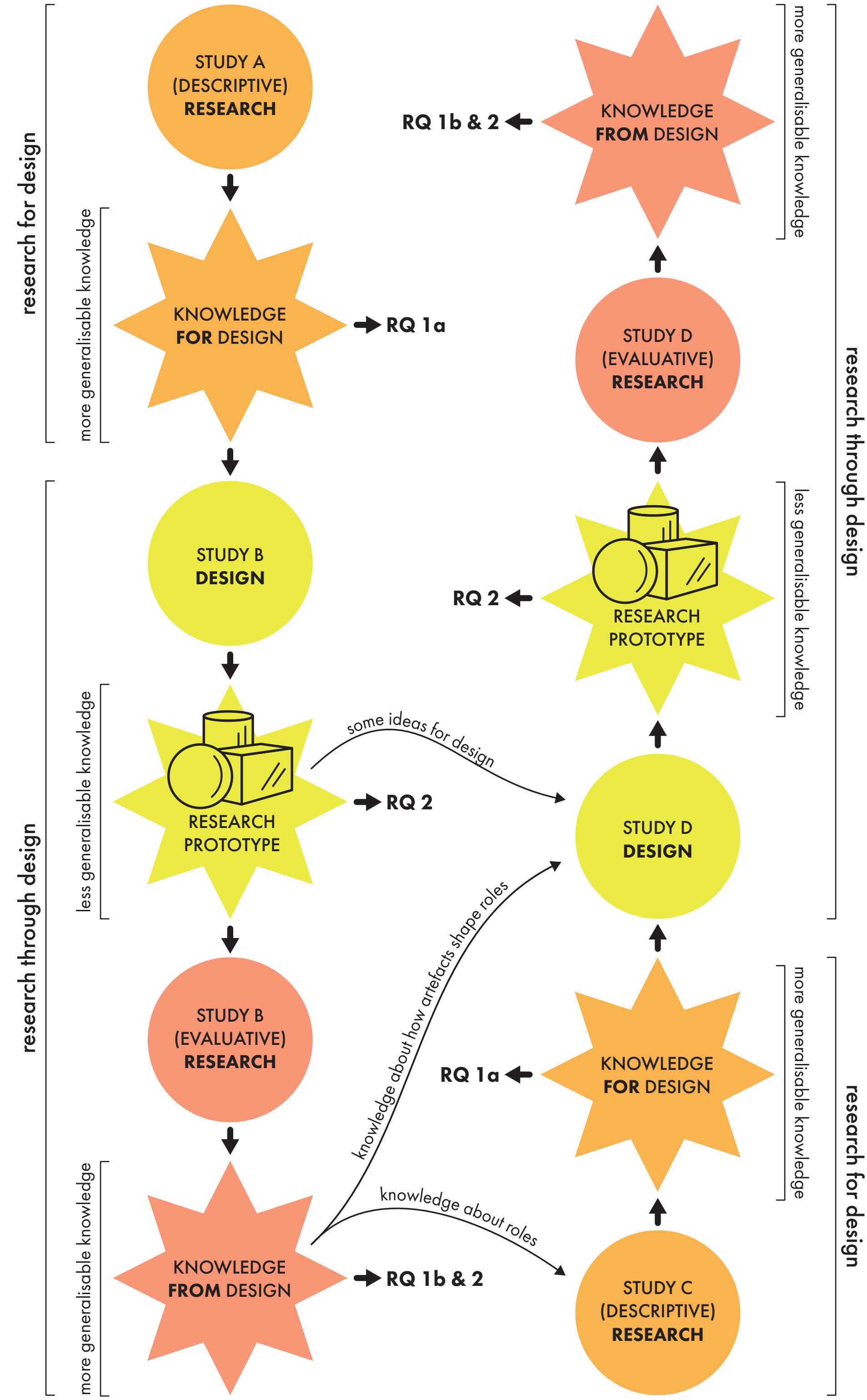

research for design
more generalisable knowledge
STUDY A (DESCRIPTIVE) RESEARCH
KNOWLEDGE FOR DESIGN
RQ 1a
research through design
STUDY B DESIGN
less generalisable knowledge
RESEARCH PROTOTYPE
RQ 2
some ideas for design
STUDY B (EVALUATIVE) RESEARCH
more generalisable knowledge
KNOWLEDGE FROM DESIGN
RQ 1b & 2
knowledge about how artefacts shape roles
knowledge about roles
KNOWLEDGE FROM DESIGN
RQ 1b & 2
more generalisable knowledge
STUDY D (EVALUATIVE) RESEARCH
research through design
RESEARCH PROTOTYPE
RQ 2
less generalisable knowledge
STUDY D DESIGN
KNOWLEDGE FOR DESIGN
RQ 1a
more generalisable knowledge
research for design
STUDY C (DESCRIPTIVE) RESEARCH

Figure 3.2 (left). *Design research as carried out in this thesis.*

seeds of transferable methods and guidelines which are more generalisable and more abstract than knowledge about what can be designed (cf. Höök et al., 2015; Stappers & Giaccardi, 2017). Third, evaluation of research prototypes generated knowledge about *how artefacts contribute to shaping everyday life* interpreted as strategies for design – the most generalisable and abstract type of knowledge from design generated in this thesis.

Stappers and Giaccardi (2017) point out that a 'research prototype', a prototype created with the intention of being part of a research process, should not be confused with a 'concept for products', an early version of a product intended for the consumer market. Nevertheless, if a research prototype is going to be used by research participants *in situ* for longer studies the demand on the quality of finish of the research prototype might be almost as high as for a product (Stappers & Giaccardi, 2017).

3.2.2 Integrative research (i.e. mixed methods approach)

Throughout the thesis I have used an integrative research methodology in which I have mixed qualitative and quantitative data (cf. Johnson & Onwuegbuzie, 2004). I have in all descriptive and evaluative studies combined collection of quantitative and qualitative data at roughly the same time. I have then typically analysed the qualitative and quantitative data separately by comparing and relating the 'qualitative' and 'quantitative' insights. After this, I integrated both sorts of insights into the interpretation of the overall findings, in what is known as a convergent mixed methods study design (cf. Creswell, 2014). Examples of qualitative data collection methods used are interviews and examples of quantitative sources of data are questionnaires (see also Tables 3.2 to 3.8 in the following sections).

3.2.3 Research context

This thesis has been supported by the energy utility Göteborg Energi AB and the studies focused on the area in which the energy utility operates, namely the city of Gothenburg, Sweden. Focus has further been on the types of energy that the utility provides, including district heating, electricity, and energy-related services that the utility provides or could provide (such as energy-related services enabled by smart energy systems, for instance energy-efficiency services). See Figure 3.3 for an overview of Gothenburg's energy system. Göteborg Energi produces, distributes, and sells energy as well as energy-related services to businesses, organisations, and private households in Gothenburg. The utility can therefore be said to be involved in many facets of energy systems. However, this thesis focuses on private households, as described in Section 1.4.

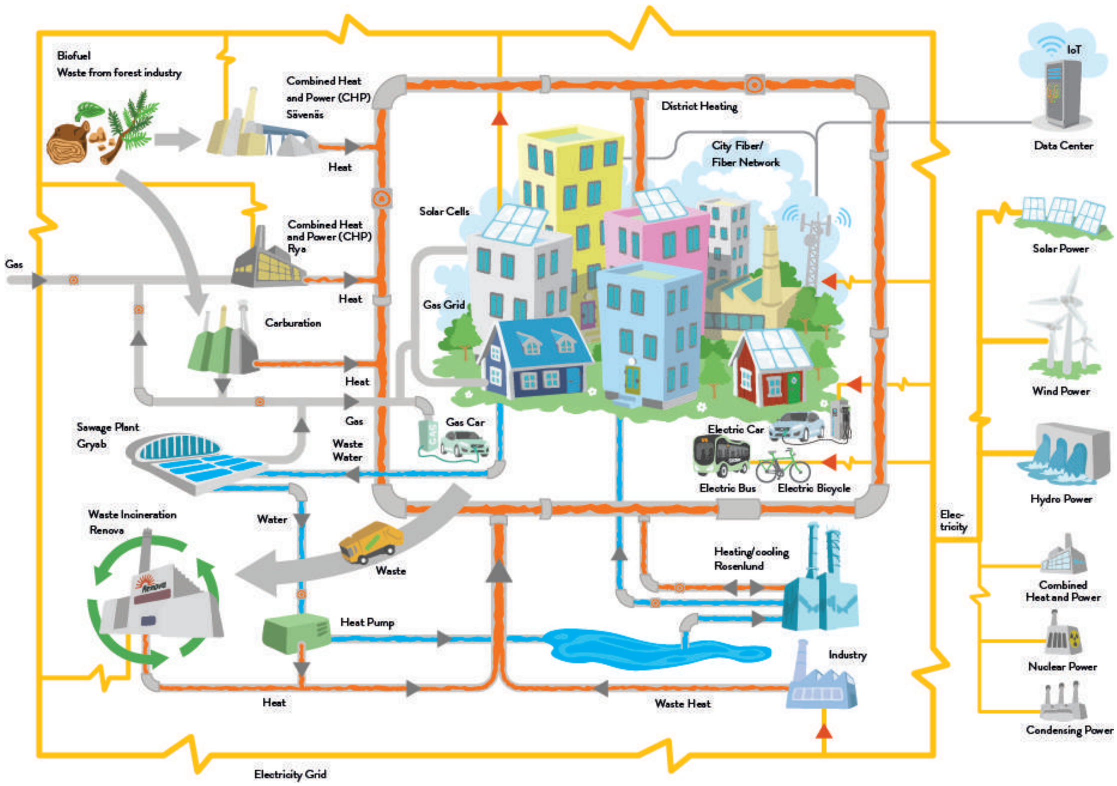


Figure 3.3. *An overview of the energy system in Gothenburg. Illustration by Göteborg Energi (reprinted with permission).*

3.3 RESEARCH PROCEDURES

A variety of research procedures were employed in the research: different ways of recruiting participants, a mix of methods for data collection, and different strategies for analysing data. The specific procedures of each of the non-empirical and the empirical studies are described in the following sections (3.3.1 to 3.3.6). Section 3.3.7 provides an overview of the tactics used to confirm findings in all empirical studies.

3.3.1 Paper X (Layers of Design)

Paper X, the first paper appended to this thesis, presents a framework useful for design. The development was done by establishing criteria for a framework and then reviewing existing frameworks in relation to those criteria. When none of the existing frameworks filled all the criteria, Anneli Selvefors, Helena Strömberg, and I developed the proposed Layers of Design framework based on a preliminary version suggested by Selvefors and Stömberg, see also Table 3.2.

Table 3.2. *Procedures and methods for Paper X.*

RQ	Study	Type	Aim	Procedures & methods	Output
n.a. (framework development)	n.a.	Literature/ theory-based conceptual research	Develop a framework useful for design	Review of existing framework Conceptual work of developing a new framework	The framework Layers of Design presented in Section 2.2.1 and in Paper X

3.3.2 Study A (Roles in district heating systems)

The first study, Study A, aimed at exploring how householders understand and make use of district heating in their everyday lives. Although covering a slightly different theme than research question 1a, it was possible to infer what roles householders play, and consider playing, in current district heating systems, and what role district heating plays in householders' everyday lives. The study was divided into two parts, Study A1 and Study A2. In total, there were 59 participants in Study A, some participated in both parts and some in one of the parts only.

Table 3.3. *Procedures and methods for Study A.*

RQ	Study	Type	Aim	Procedures & methods	Output
1a: what roles?	Study A	Descriptive study	Exploring thermal comfort in relation to how householders use heating and hot water (part 1) Residents' views of their roles in current DH systems (part 2)	Self-selection of participants Integrative research: questionnaires (quant), diaries (qual and quant), interviews (qual), generative techniques (qual), and sensitising (qual) Thematic content analysis to summarise findings into emerging themes	Influencing factors for households' use of heating and hot water presented in Paper A Background for designing Study B

Participants

For Study A1, participants were recruited through self-selection after advertisements in the local newspaper, libraries, and super markets (approx. 19), through e-mails to university students and employees (approx. 12), and through ads in social media (approx. 4), in total 35 participants (21 women, 14 men, mean age 40). The study was described as a study about heating and participation was rewarded with two cinema tickets. As Study A1 was about heating in general, participants with different types of homes and heating systems were recruited to capture the variety of ways in which people stay warm.

Study A2 concerned district heating specifically and householders with district heating were therefore recruited. Type of home and ownership were regarded as important (as found by Palm & Isaksson, 2009) and households were recruited from: (i) co-operative (tenant-owner) apartments (n=9), (ii) rented apartments (n=10), and (iii) private (semi-)detached houses (n=11). The participants in Study A1 who matched those requirements were invited to participate also in Study A2 and eleven participants in ten households did so. The remaining participants were recruited through questions to the local energy company's customer base (n=8), e-mails to my acquaintances, to my colleagues, or to acquaintances of the participants (n=10), and through ads posted in suitable apartment buildings (n=2). In some of the 30 participating households, two householders participated, resulting in a total of 35 participants (19 men, 16 women, mean age 44). The study was described as a study of householders' opinions about district heating and participation was rewarded with a 200 SEK voucher.

Data collection

Participants in Study A1 were invited to a meeting at Chalmers where they filled in questionnaires investigating what emotional reactions are elicited in different thermal situations and what adjectives best describe the characteristics of the situations (see Renström & Rahe, 2013 for details). The participants were then introduced to a thermal diary that they were asked to fill in over the course of one week. In these thermal diaries, the participants were asked to note when and where they experience thermal discomfort, what body parts were affected, and what measures were taken to regain thermal comfort (if any), and how they felt about it. In addition, the participants in Study A1 and Study A2 filled in (the same) questionnaire concerning demographics and general energy related issues.

The second part, Study A2 included a visit to the participants' homes, except for the participants who specifically preferred to meet at Chalmers. The visit was preceded by sensitising the participants (cf. Sleeswijk Visser et al., 2005) through an annotation exercise. The one and a half hour visit comprised generative exercises (cf. Kuniavsky et al., 2012) and a semi-structured interview.

In the annotation exercises, the participants were asked to label things they use to stay warm and to (access) hot water with five different statements about energy printed on arrow-shaped notes (inspired by Lockton et al., 2011; Lockton, Nicholson, et al., 2014), see Figure 3.4. The participants received a packet of notes and instructions by mail before the visit and were asked to show what they had annotated during the visit.

The tours around the annotated items in the participants' homes were followed by generative exercises in which the participants were asked to sketch their understanding

Figure 3.4 (right). *An example of the annotation exercise intended to sensitise the participants to the topic of heating, hot water, and energy.*


Jag undrar hur mycket energi den här grejen använder?
Kommentarer?
Jag tror att den här grejen använder lite energi.
Kommentarer?
Jag tror att den här grejen är väldigt energieffektiv.
Kommentarer?
M2005
Jag undrar hur mycket energi den här grejen använder?
Kommentarer?

of their heating and hot water system, including the energy supply method. They were also asked to sketch their understanding of their daily and annual heating and hot water consumption as a graph.

The generative exercises were followed by semi-structured interviews. The interview guide covered four areas: the participants' interaction with the heating and hot water system, their view of their heating and hot water consumption, how technologies in the home relate to consumption, and ideas about reducing consumption. The responses were noted by me. Audio recordings of the interviews were used as backup to the notes.

All participants were informed about the aim of the study. They verbally agreed to being recorded and for their anonymised data to be shared. After the study, the findings from Studies A1 and A2 were summarised and sent to the participants in order to show the them the end result.

Analysis

The interviews were coded into emerging categories in the qualitative data analysis software NVivo. Based on these emerging categories, six over-arching themes were defined: environmental issues (in relation to energy consumption), expectations on (thermal) comfort, control over heating, interaction (with heating and hot water systems), understanding (of heating and hot water systems), and pursuit of thermal comfort. After this, the results from the annotation exercise, the generative exercise, thermal diaries, and the questionnaires were categorised according to these six themes. This combined analysis can be found in Paper A.

3.3.3 Study B (Design & evaluation of technology probe kit)

The aim of Study B was to explore the possibilities of enabling new ways of doing in the context of thermal comfort. Based on ideas from technology probes (Hutchinson et al., 2003) and experience prototyping (Buchenau & Suri, 2000), 18 households in apartments with district heating were equipped with a simple, flexible, and adaptable prototype for person heating put together into a technology probe kit.

Design phase

The design and prototype development process was not aimed – as in design processes in industry – at finding a commercially viable product, but a research prototype: an artefact that "…plays a central role in the knowledge-generation process" (Stappers & Giaccardi, 2017, section 43.1.4) or "artifacts intended to transform the world from the current state to a preferred state" (Zimmerman et al., 2007, p. 5).

I have in the design phases of both Studies B and D (alone and together with design professionals) initially ideated through generating concepts in the shape of simple sketches and mock-ups, see Figure 3.5. When generating concepts early in the design phase, I have not limited myself to what is technically or economically

Table 3.4. Procedures and methods for Study B.

RQ	Study	Type	Aim	Procedures & methods	Output
2: what artefacts?	Study B	Explorative design in Study B	Ideating concepts for a research prototype and designing a research prototype	Making use of study A and complementing with benchmarking and getting energy professionals' views on district heating Writing a design brief Ideating with professional designers Designing and building a prototype	Insights into what could be designed Prototype kit for Study B
1b: shaping roles? 2: what artefacts?		Evaluation of prototype *in situ*	Understand how technology shapes the roles householders take	Volunteers within a multi-family building, final selection based on criteria Integrative research: questionnaires (quant), technology probe study (qual), contextual interviews partly based on SAKS (Strömberg & Karlsson, forthcoming) Thematic content analysis to summarise findings into emerging themes	Knowledge about designing for alternative ways of doing as presented in Paper B

feasible in the projects and these concepts therefore best show the *ideas*, that is to say the meaningful and deliberately different features. When these concepts later were developed into something that could be evaluated *in situ*, some of the ideas became less explicit and less prominent due to the practicalities of prototype building. In the research prototypes it was therefore more difficult to see which features of the prototypes were meaningful and deliberately different and which features were, as Stappers and Giaccardi (2017) put it, 'contingent', i.e. which might as well could have been different. (An example of a contingent feature could be the colour of a research prototype intended to explore sound in interaction, while the colour could be a meaningful and deliberately different feature of a research prototype used to explore visual aesthetics.) I have therefore presented both concepts and research prototypes (following for instance the style of Katzeff, Wessman, et al., 2017) and added a framing (cf. Stappers & Giaccardi, 2017) which explains what features are meaningful and deliberately different and what features are contingent. Framing is suggested to enable more people than the close research community to understand this difference (Stappers & Giaccardi, 2017). The concept, research prototype, and framing for Study B are presented in Section 5.1.1.

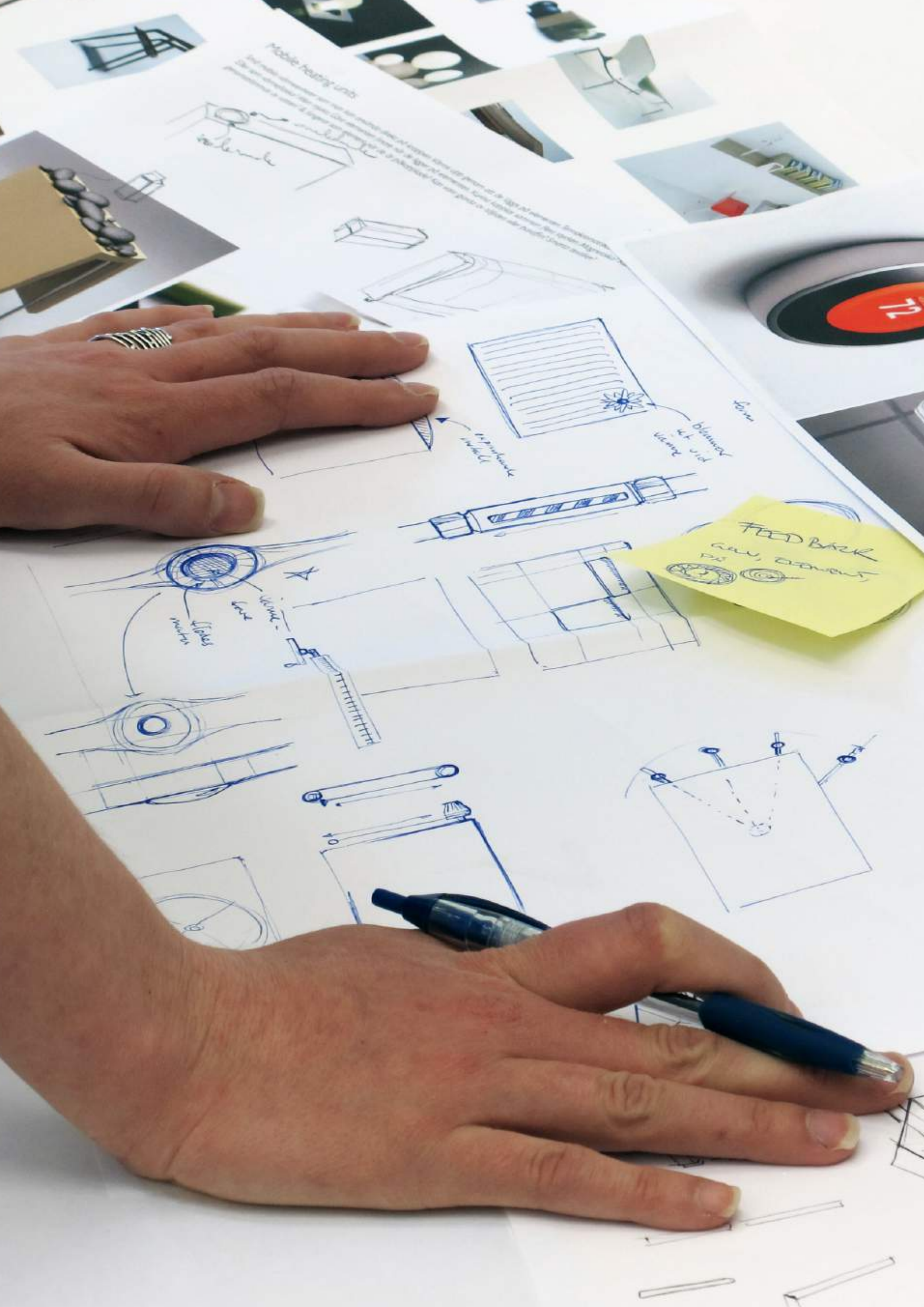


Figure 3.5 (left). *Early sketches in the design phase of Study B (photo by Anneli Selvefors).*

The steps in the design process for Study B included:

- structured e-mail interview with five district heating experts at Göteborg Energi working with district heating innovations,
- compilation of a design brief based on the results from Study A,
- ideation (on my own) based on the design brief,
- benchmarking my ideas with existing solutions and suggested concepts in academia and elsewhere (e.g. industry),
- study visit to a house re-built to demonstrate the possibilities available with district heating (Zinko, 2006),
- continued ideation with design professionals,
- selection of what ideas to prototype based on how suitable they were for evaluation *in situ*, and
- research prototype building.

To make it possible to use simple, flexible, and adaptable technology (as suggested for technology probes (Hutchinson et al., 2003) without alterations of existing infrastructure, the technology probe kit included two types of devices for person heating: heating pads and hot water bottles.

In addition, the kit included an information sheet briefly describing what district heating is and how the heating devices worked, as well as explaining how using sources of excess heat in the home correspond conceptually to the way a district heating system uses available heat sources in the city. The participants also received material for self-documentation. The details of the technology probe kit can be found in Paper B.

Participants

Participants were recruited from one single leaseholder association to avoid differences in local conditions. Recruitment was carried out through a survey on perceptions of home and living standards, domestic heating, and environmental opinions distributed in parallel with another research project (see Hagbert, 2016 for details). In the survey, there were an option for respondents to volunteer for a follow-up study which was Study B. Two cinema tickets were offered as compensation. Out of 156 respondents, 67 volunteered for this study. For 31 of those volunteers, person heating was assumed to be of some relevance as they indicated in the survey that they considered themselves to feel colder than others, and/or stated that they take action when being cold. The number of participating households was limited to 20 for logistical reasons, while trying to maintain the spread in environmental opinions, age, and gender. In total, 18 households completed the study, with two participants in two of the households.

Drop-outs stemmed from not having used the technology probe kit and not wanting to be interviewed. For details, see Paper B.

Data collection

The participants received the technology probe kits in the beginning of March 2014 and kept them for approximately one month. The outdoor mean temperature was 6 degrees Celsius (SMHI, n.d.). At the start of the study all participants were informed that the aim of the study was to see if, and how, people would like to use portable heating units and that the heating units were designed based on the idea that heating a person could be more purposive than heating up a room. Finally, participants were recommended to use the heating devices when feeling uncomfortably cold instead of turning up the space heating and they were encouraged to consider lowering their indoor temperature.

The study concluded with semi-structured interviews in the participants' homes (encouraged), the leaseholder association's office, or at Chalmers (one participant). The interview guide covered the participants' use and experience of the technology probe kit partly based on questions from the Strömberg-Karlsson Acceptance Scale (SKAS) (Strömberg & Karlsson, forthcoming), suggestions for improvements to the heating devices, and changes resulting from kit use, if any. The interviews lasted from 15 to 30 minutes. Photos and notes taken by the participants during the study were also collected at the interviews.

All participants were informed about the aim of the study. The participants verbally agreed to being recorded (in the final interview) and that anonymised data about them could be shared. After completion, the results from the study were summarised and e-mailed to those participants who wanted to be informed. Paper B was shared on request.

Analysis

The interviews were recorded and later transcribed. All data (transcripts of interviews, images, and notes) were jointly analysed with NVivo. The data was first coded using deductive coding (cf. Miles et al., 2014), in other words grouped into predefined themes given by the topics in the interview guide. This first cycle coding provided a rough categorisation of how the participants used the heating devices in their thermal comfort activities. This categorisation was followed by a second cycle of inductive coding (cf. Miles et al., 2014) and focused on changes to thermal comfort activities and beyond to provide more insight into the participants' activities, probe use, reasoning, and changes in ways of pursuing thermal comfort. The findings were summarised in Paper B.

3.3.4 Study C (Roles in smart energy systems)

The third study, Study C, aimed at exploring what roles householders consider playing in future smart energy systems and if (and how) products, services, and/or systems could support those roles. The main method of exploration was generative group sessions with sixteen participants residing in a living lab – a building designed as a home for people and at the same time functioning as a research and demonstration arena for academia and industry.

Table 3.5. *Procedures and methods for Study C.*

RQ	Study	Type	Aim	Procedures & methods	Output
1: what roles?	Study C	Descriptive study	Exploring opinions about smart energy systems Describing roles householders are interested in taking in smart energy systems and the tools they need to be able to take those roles	Volunteers in HSB LL Group sessions inspired by context-mapping (qual) and C.A.R.E. (qual) including sensitising (qual and quant), contextualising (qual), generative techniques (qual), and reflections (qual) Thematic content analysis to summarise findings into emerging themes and interpretation to find roles within themes	Knowledge about considered roles and possible tools in smart energy systems as presented in Paper C Background for designing for Study D

Recruiting participants

All residents in the living lab were invited to participate in the study via posters at the entrance, Facebook, and e-mail. In total, sixteen residents (8 women and 8 men, age span 18-60) participated.

Data collection

The study consisted of two parts: a booklet with assignments intended to sensitise the participants on the topic of energy and future smart energy systems (see Paper C for details) and generative group sessions. The procedure was inspired by context-mapping, a way of gaining deep insights about prospective users of new technologies (Sleeswijk Visser et al., 2005).

The study included four generative group sessions, with three to six participants in each. Three sessions were led by me with the assistance of one colleague and one session was led by two colleagues. All sessions were recorded. For details, see Paper C.

To make the context of energy use 'present' (cf. Petterson, 2018), the participants started the sessions by marking where they carry out, think, and talk about energy-reliant activities on a floor plan. The participants then watched films[1] about life in smart energy systems (made by Goulden et al. (2014)) indented to provide

1 Accessed at http://horizonenergy.blogspot.se

information about smart energy systems and to facilitate imagining everyday life in smart energy systems).

Thereafter, the participants made collages (with text, sketches, stickers, and provided pictures) describing what a day could be like in a smart home connected to a smart energy system according to their preference. The participants then described their future day to each other. The intention was to go beyond what participants "say, think, and do" and into what they "know, feel and dream" through the use of generative techniques (Sleeswijk Visser et al., 2005, p. 4).

A discussion on energy and sustainability (mostly in terms of reduced negative environmental impact) followed, including topics such as: what is required for a more sustainable energy future; different actors and their responsibilities; if there is a need for any products, services or systems, and; if so, their design. The discussion was indented to encourage reflection about roles in smart energy systems as well as if and how energy-reliant and energy-managing artefacts could support roles.

Finally, the participants were asked to imagine two helpful, smart, and skilled tiny living beings present everywhere in their future home and energy system – 'Smarty' and 'Handy'. The participants were then asked to complete statements about what they would like 'Smarty' to tell them and 'Handy' to do, and what their own role should be in future smart energy systems. This final part was inspired by Vandenberghe and Slegers (2016) who in their study utilised the fact that people anthropomorphise complex technology to make it comprehensible.

All participants were informed about the aim of the study. The participants verbally agreed to being photographed and recorded. They also agreed to allow anonymised data about them to be shared.

Analysis

In the analysis, I started by identifying what it was that participants did not question or discuss a lot, as they seemed to be in agreement. Then, I identified roles that the participants wanted to play in future smart energy systems. However, the participants did not explicitly talk about roles in smart energy systems; instead, they discussed what could be conceptualised as different *orientations*: their understanding of energy systems, their opinions about them, and the type of interaction they prefer. In the analysis, data (transcripts of sayings in the sessions, pictures, and written comments produced in sessions or in booklets) was therefore coded inductively (cf. Miles et al., 2014) into orientations. These orientations were then summarised in a descriptive manner. Based on the summaries I inferred what those roles those orientations implied.

During the sessions, as one participant described an orientation, the participants often responded by bringing up an opposing orientation. An opposing orientation could therefore be identified for almost all orientations – and thus also an opposing role.

The participants also discussed energy-reliant and energy-managing artefacts. Those were coded in an inductive manner (cf. Miles et al., 2014) and related to the orientations/roles. See Paper C for details and for a complete overview of Study C.

3.3.5 Study D (Design & evaluation of Ero)

The aim of Study D was to explore the possibilities of reconnecting energy supply and demand by enabling new ways of organising energy use. Seven residents in a living lab were equipped with a smart home and energy system and reported on their experiences of using the system for four months.

Table 3.6. *Procedures and methods for Study D.*

RQ	Study	Type	Aim	Procedures & methods	Output
2: what artefacts?	Study D	Explorative design in Study D	Ideating concepts for a research prototype and designing a research prototype	Making use of Studies A, B, and C, complemented with a small study on householders with smart home technologies, complemented by benchmarking Ideating with design professionals within another project Finalised design by project assistant	Insights into what could be designed The prototype Ero used in Study D
1b: shaping roles? 2: what artefacts?		Evaluating prototype *in situ*	Understand how artefacts shape the roles householders take	Volunteers in HSB LL Integrative r esearch: Evaluation of Ero *in situ,* questionnaires (quant) and contextual interviews (qual) Thematic content analysis to summarise findings into emerging themes	Knowledge about designing in smart energy systems and how artefacts shape what roles are considered and performed, presented in Paper D.

Design & development

Just as for Study B, the design process of Study D aimed at creating a research prototype (cf. Stappers & Giaccardi, 2017) and not a commercially viable solution. As the prototype was indented to be evaluated for a longer period of time, efforts were directed towards concepts that could be prototyped with sufficient quality of finish (cf. Stappers & Giaccardi, 2017).

As described in Section 3.3.3, concepts and a framing can be used to communicate the essence of a research prototype, that is to say which features are meaningful and deliberately different and which are contingent (cf. Stappers & Giaccardi, 2017). In Section 5.1.2 the finished prototype is therefore presented together with an earlier concept and a framing.

The final prototype was based on a concept, called an Activity Organizer, designed in a separate project as a collaboration between myself and professional designers Katharina Merl and Mikael Sundgren at Boid, a design bureau affiliated with Chalmers. The process of designing the Activity Organizer included the following steps:

- semi-structured interviews with two pilot users of a home energy management system called Green IT Homes (for information about Green IT Homes, see IMCG, 2012);
- semi-structured interview with one of the project leaders of the development of Green IT Homes;
- semi-structured interview and home visit to a person who was finishing his own smart home with the aim of going off the energy grid, so-called 'off-grid';
- benchmarking existing solutions;
- ideating concepts based on the interviews, benchmarking, and literature review;
- selecting and refining one concept, including defining overarching principles, functions, and designing the user interface;
- developing a research prototype testing one aspect of that concept; and
- small-scale evaluation of that prototype.

A version suited for a living lab was developed, called Ero, whose main overarching principles and functions were based on the Activity Organizer. During my parental leave, the specific functions and appearance of the user interface were adapted to the living lab by Sofie Andersson, at that time serving as project assistant at Chalmers. One important adaptation was to include both private areas and shared areas in the system as there are both in the living lab. Another adaptation was to the technical prerequisite regarding power outlets in the living lab and to adapt the user interface design to the format of an iPad mini.

Ero was thereafter prototyped by software engineers at Chalmers, under the lead of Andreas Jonasson, Business Developer at IT System and Services. The installation of Ero in apartments was then carried out by Jonasson, assisted by Andersson, and me.

Participants

Due to technical reasons, only ten participants could evaluate Ero and they were invited to participate in the study through posters in the living lab, e-mails, and letters. Eight participants initiated the study and seven completed all parts of the study. The drop-out was for personal reasons. Among those who could evaluate Ero, a significant majority were men so there were thus fewer women in Study D (details of the exact number of women are left out to ensure the participants' privacy). The age of the participants covered a wide range (details of age are left out to ensure the participants' privacy). Both university students and people in employment took part in the study. The participants lived alone in their rooms.

Data collection

Study D was performed in six steps during the autumn/winter season of 2018/2019. In mid-September, an online questionnaire was sent to the participants covering what roles they were interested in playing in the smart energy system, their attitude to sustainability, and organisation of everyday life. At the end of September, all participants were invited to a voluntary introduction event covering the background of the system and how to use it. Three participants joined the event. In early October, Ero was installed for the participants. Upon installation the participants were also interviewed using a semi-structured interview guide, either by Andersson or by me. The guide covered demographics, life in a living lab, organisation of everyday life, and questions about what roles the participants were interested in playing in the smart energy system and their opinions about more sustainable energy systems. As part of the latter two aspects, all participants marked their positions on scales covering the roles identified in Study C. The whole visit took around 1 hour, of which the interviews took 15 to 30 minutes. The interviews were recorded. For Study D, the system was in place from October to January. During that time, I had occasional contact with some of the participants to solve reported technical issues. This period also included software updates and technical improvements. In mid-January, the same questionnaire as in September was sent to the participants but expanded with questions about how the participants used Ero and their thoughts about it. The Strömberg-Karlsson Acceptance Scale was used to get an overview of the participants' opinions (Strömberg & Karlsson, forthcoming). The study terminated at the end of January/beginning of February with a semi-structured interview. The interviews were led by me and I was at a few occasions accompanied by Andersson. The interview guide covered the following themes:

- how the participants had used Ero and what they thought about Ero,
- what the participants thought of the rather low level of automation in Ero,
- what the participants thought about having a personal energy threshold,
- if and how Ero aligned with everyday life,
- organisation of everyday life and if it had changed,
- if and how Ero contributed to more or less energy use and more or less peaky energy use
- what roles the participants were interested in playing in smart energy systems and if they had changed,

- if the roles enabled through Ero fitted with the roles the participants wanted to play, and
- opinions about more sustainable energy systems and if it had changed.

As part of the latter three, all participants again marked on scales covering the roles identified in Study C. They were asked to mark where they were at the time of the final interviews and also where they thought they had been before evaluating Ero, if they considered it to be any different. The interviews lasted 45 to 60 minutes and were recorded.

All participants were informed about the aim of the study at the first visit and also about their rights in relation to GDPR. The participants signed a consent form regarding treatment of their personal data and agreed to being recorded at the two interviews. They also agreed to allow anonymised data about them to be shared. The results from the study were summarised and sent to those participants who wanted that information. Paper D was shared on request.

Analysis

The questionnaires were analysed to find differences between responses in the first and second questionnaire using non-parametric statistics in the SPSS software (se paper D for details). SPSS was also used to prepare descriptive statistics.

Recordings from all interviews were transcribed, pseudonymised, and coded in the NVivo software. The coding was done in two cycles. In the first cycle the interviews were coded by me in an inductive manner (cf. Miles et al., 2014). I iteratively built a coding frame and included descriptions of the codes. Personal annotations were also made regarding inferences and possible explanations. Descriptive coding was mostly used in the coding, in other words summarising chunks of text in a word or phrase (cf. Miles et al., 2014). Subcoding, a detailing second-order tag (cf. Miles et al., 2014), was used to structure the codes. Simultaneous coding was used when necessary, meaning that several codes were assigned to the same chunk of text. When all interviews were recorded and the coding frame was complete, Andersson coded all the interviews in a deductive manner using the coding frame. When necessary, she also expanded the coding frame. The intercoder agreement was tested in Nvivo and was initially 0.53 (moderate agreement (Landis & Koch, 1977) or fair to good agreement (NVivo, n.d.)). Codes with most disagreement were then re-coded by Anderson and me with consensus coding, resulting in kappa 0.63 (substantial agreement (Landis & Koch, 1977) or again fair to good agreement (NVivo, n.d.)). Most disagreements related to the extent to which simultaneous coding was used.

The second cycle coding was done by Andersson and me jointly. In the second cycle coding, three questions guided our analysis: (1) how Ero had been used, (2) what happened during the evaluation (if anything), and (3) what alternatives there are to the current design of Ero, and beyond. Based on these questions, the first cycle codes were grouped into pattern codes in a deductive manner. The pattern codes were then mapped onto a network display (cf. Miles et al., 2014). In Paper D, these pattern codes were then summarised into descriptive summaries.

3.3.6 Cross-study analysis

To answer the three research questions, I analysed the data from all empirical studies in three separate analyses. In those analyses, social practice theory and activity theory were used mainly for research question 1a, activity theory for research question 1b and research question 2, and Layers of Design for research question 2. The details of the analyses are found in the following sections, after introduction of the analysis strategy used in all three cross-study analyses.

Activity (mis)match analysis

In the analyses answering research questions 1a, 1b, and 2 I identified matches and mismatches between different components of the activity systems (cf. Babapour, 2019; Bødker & Klokmose, 2011; Selvefors, 2017). The studies were not planned with this (mis)match analysis in mind and not all records of activities were therefore complete enough to be used in this analysis. The analysis was nevertheless useful to show differences between roles and to pinpoint potential improvements to the designs.

In terms of activities with less negative environmental impact, Selvefors (2017) describes that people's activities can be (i) everyday activities with everyday motives[1] such as to increase well-being (comparable with energy-reliant activities), (ii) energy-conservation activities with the motive of conserving energy to reduce negative environmental impact (comparable with energy-managing activities), and that these activities are sometimes combined into what she calls (iii) a *frugal everyday activity* with an everyday motive and an energy conservation motive, such as increasing well-being and reducing negative environmental impact. In the analysis of this last type of activity she then identifies matches and mismatches between the different components of the activity as defined in Selvefors' illustration in Figure 3.6.

By analysing the two motives as a joint frugal everyday activity it is not always clear to which motive a (mis)match relates. To highlight matches and mismatches related to reduced negative environmental impact, I separated the analysis of the 'everyday' motive and the 'energy conservation' motive, see Figure 3.7, (which Selvefors instead jointly analysed as a frugal everyday activity). The 'energy conservation' motive is relabelled to be more generic and is called *reduced environmental impact*.

An advantage of separating the analysis of the 'everyday' motive and the 'reduced environmental impact' motive is that the separated analysis clearly shows if the tool matches with one motive and mismatches with another. What it is like to use a tool (i.e. subject – tool (mis)match) in relation to the two different motives is also clarified

1 Cf. non-energy related rationalities connected to many activities in homes, such as getting comfortable or enjoying a dinner, described and discussed by Naus (2017).

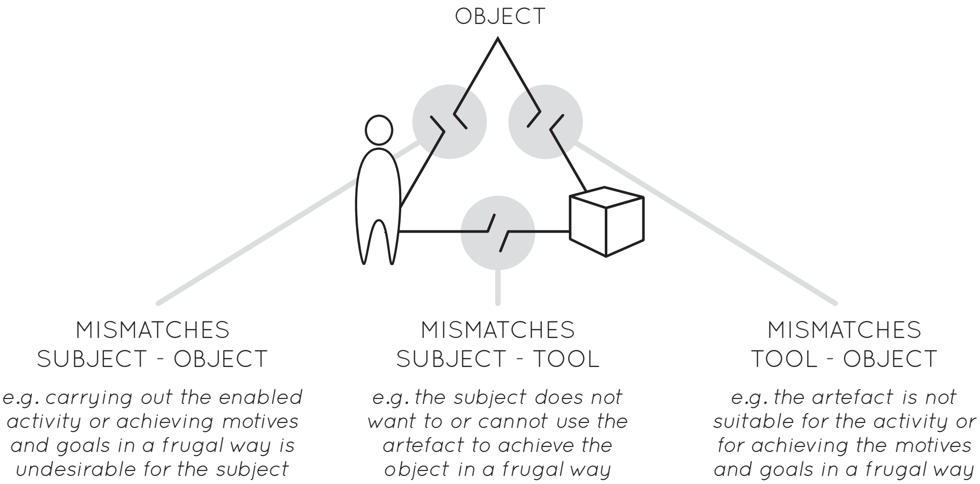


Figure 3.6. *Potential mismatches in frugal everyday activity with the motive of increasing well-being and reducing environmental impact (copied with permission from Selvefors, 2017, p. 52).*

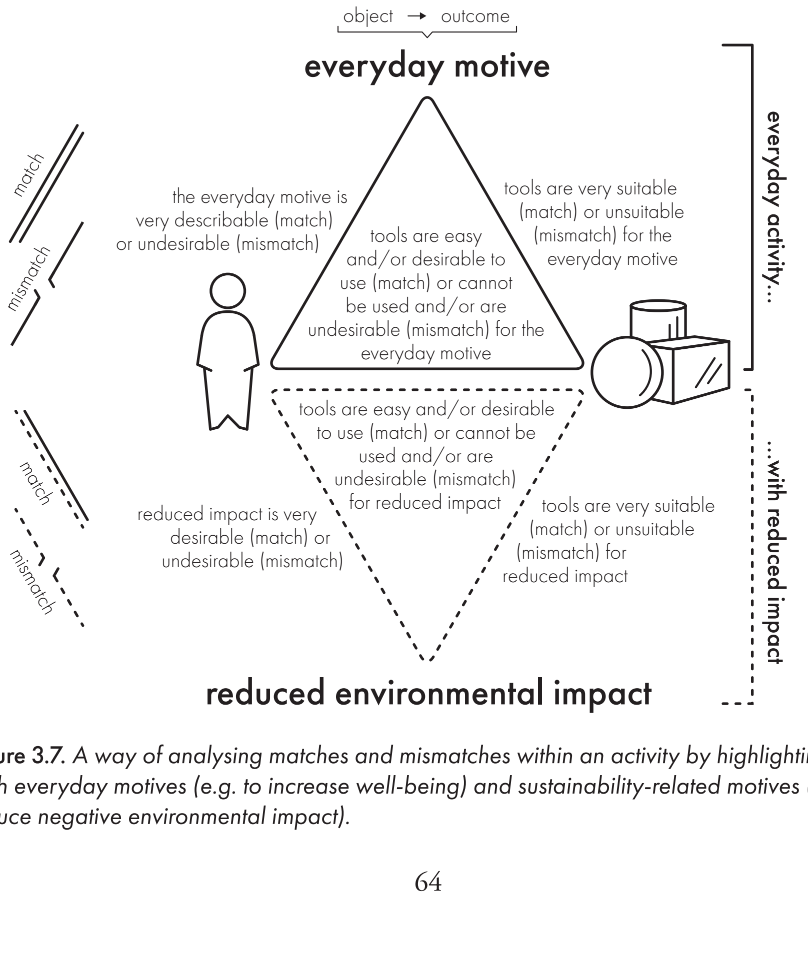


Figure 3.7. *A way of analysing matches and mismatches within an activity by highlighting both everyday motives (e.g. to increase well-being) and sustainability-related motives (e.g. to reduce negative environmental impact).*

as well as whether there is a difference. Finally, someone showing little interest in reducing negative environmental impact appears as a mismatch between the person and that motive (i.e. subject – motive (mis)match).

Cross-study analysis – RQ 1a (What roles?)

Empirical data from Study A and Study C was used to answer research question 1a: What roles could householders, through their everyday lives, play in district heating systems, smart energy systems, and combinations of the two? (See Table 3.6). However, the data from these studies needed interpretation within as well as between studies. I therefore revisited the data and analysed it anew in three steps, see steps 1-3 below. The analysis was an inductive data-driven process – a bottom-up process – and not theory-driven (cf. Miles et al., 2014).

Table 3.6. *Procedures and methods for cross-study analysis for RQ 1a.*

RQ	Study	Type	Aim	Procedures & methods	Output
1a: what roles?	n.a.	Cross-study analysis for RQ 1a	Synthesising findings related to roles across studies	Synthesising the results from all studies, but mainly Studies A and C. Making use of social practice theory, activity theory, and especially activity (mis)match analysis.	Knowledge about what roles householders could play presented in Chapter 4

In an attempt to deepen understanding of the empirical data I then revisited the results from the analysis in steps 1-3 for conceptualising and labelling the findings from a theoretical perspective. I first analysed the result with a social practice perspective (step 4) and then with an activity-oriented perspective (step 5). This theory-driven analysis was additionally conducted to investigate whether the findings from the analysis in steps 1- 3 would be supported by the theories. The use of different theories is a strategy for triangulation (cf. Miles et al., 2014)

Step 1. Identification of roles people consider. Roles in relation to energy systems were not something that the participants in Study A and Study C explicitly expressed. Roles, as defined in this thesis, could instead be identified through understanding how the roles were manifested: (i) what energy-reliant and energy-managing activities people (want to) engage in or (want to) not engage in, (ii) how these activities are performed, and (iii) what outcome people want these activities to have in relation to the energy system. Recurring similarities in topics related to these three manifestations of roles were described, summarised, and grouped into different themes in an iterative manner. In this process, earlier ways of categorising the data (see Papers A and C) were used when helpful, but I did not limit this renewed categorisation to those categories.

The themes mostly include data *either* about the district heating system (Study A) *or* future smart energy systems (Study C). The summaries of the themes differed slightly from each other due to the two different characters of the respective studies. Study A consisted partly of interviews with (one or several) members of one household while Study C consisted mainly of focus groups in which one participant's opinion was often opposed by another's. Some of the thematic summaries therefore show a range in opinions, while others have less of this divergence.

From the manifestations of roles described in the thematic summaries I inferred different roles. In this inference, a role was not understood as being manifested in one single activity, how that activity was performed, and what outcome it had, but instead on (1) what *types of* energy-reliant and energy-managing activities participants considered and performed, (2) *similar characteristics* of how these activities were performed, and (3) what *types of* outcome the participants wanted these activities to have in relation to the energy system. This meant that the roles emerging from a similar theme had different characteristics, such as being passive or active. The roles are however not independent and free from interrelations, as discussed also in Paper C. Step 1 of the analysis, the identification of roles, resulted in nine themes with one to two roles tied to each, in total 16 roles.

Step 2. Emerging meta-roles. In step 1, I identified 16 roles that the participants considered (and maybe performed), but that is not the same as all the roles people *could* play (cf. RQ 1a). To identify roles that the participants did not either consider or perform but could still play, I had to add to the identified roles in some way. I decided to do so by exploring interdependencies and interrelations between the considered roles to find similar roles that could be assumed to be conceivable even though they were not considered (cf. perceived action space and considered action space in Strömberg (2015)). I therefore revisited the thematic summaries and roles and looked for connections. I found that some of the themes and their connected roles had a common 'flavour'. (When I later explored this 'flavour' with a social practice theory perspective, I found that the similar 'flavour' could be described as a similar *image*, see below.) The themes and their connected roles could therefore be grouped through an iterative process into emerging clusters with similar flavour, ending up with three clusters. I called these three clusters *meta-roles* as they overarch the 16 roles. When describing the meta-roles, I also described the common principles for the considered roles that the meta-roles overarched so that the meta-roles became more abstract or general than the roles. As the meta-roles were more abstract, there were more roles than the ones considered by the participants that fitted within them. Roles that were not considered were still assumed to be *conceivable* as they relied on the same principles as the considered ones.

Based on the empirical findings in my studies I have not been able to determine what implications the meta-roles would have in terms of reduced negative energy-related environmental impact. Nevertheless, it was possible to reflect on the possibilities based on other people's work and that reflection is presented in the discussion of this thesis (see Section 6.2.3).

Step 3. Framing meta-roles. To lay the basis for research question 1b – How do energy-reliant and energy-managing artefacts shape what roles householders consider and perform? – I conceptualised what I found to be framing the meta-roles, and especially if and how artefacts (understood as layered, as in Layers of Design) can be found to frame the meta-roles. To do that, I revisited empirical data from Studies A and C, interviews with district heating experts at Göteborg Energi, the interviews that were part of the design process of Study D, and records of informal discussions with employees of Göteborg Energi. In this data, I identified and grouped aspects that shaped roles and analysed whether these aspects could also shape meta-roles. Five aspects were identified, and I considered these aspects to, when taken together, become a *frame* that *frames* the meta-roles. I then described how these aspects framed the meta-roles (see Chapter 4).

Step 4. Revisiting meta-roles with a social practice perspective. To deepen the understanding of the empirical data, I revisited the meta-roles from the perspective of social practice theory. In this analysis, I first found that meta-roles can be described as a way to look at practices – or actually bundles of practices as the different practices that are part of a role are interconnected (cf. Spaargaren et al., 2016) – in a more zoomed-out way that makes it possible to grasp recurring patterns (Spaargaren et al., 2016). Secondly, I found that within a meta-role, all practices had similarities when it came to the shared *image* of the role householders play in relation to the energy system – this was the 'flavour' I had previously noticed. When using social-practice theory to consider these meta-roles further I realised that the practices also expected similar *types of skills* in relation to the energy system and made use of similar types of energy-related *stuff*. Revising the meta-roles with a social-practice theory perspective was also a way to zoom out, not only as the roles and the meta-roles described the practice-as-entity better than pre-analysis data from the studies, but also as the meta-roles in a sense describe larger bundles of practices, i.e. larger social phenomena (cf. Spaargaren et al., 2016). This social practice-oriented revisit of the meta-roles is described in Section 4.3.

Step 5. Revisiting meta-roles with an activity-oriented perspective. To see if the meta-roles could be useful to explain the roles individuals considered and performed, I revisited the meta-roles with an activity-oriented perspective. As I have elaborated on for instance in Section 2.1.3, I consider activity theory to be better suited for understanding empirical data about individuals' doings and individuals' stories of changes in socio-technical systems of doings (i.e. practices or activities). A revisit of the meta-roles with an activity-oriented perspective also allowed me to highlight what importance design characteristics of artefacts have, if any, as activity theory is well equipped for doing that (see my argumentation in Section 2.1.3). In activity theory, an activity is the smallest meaningful unit of analysis. In my analysis, I therefore analysed how everyday activities are typically carried out within the three different meta-roles.

To understand what was typical, I analysed several individual stories describing different everyday activities and identified recurring types of matches and mismatches using the activity (mis)match analysis previously outlined.

Cross-study analysis – RQ 1b (Shaping roles?)

To answer research question 1b – How do energy-reliant and energy-managing artefacts shape what roles householders consider and perform? – I analysed the data from the evaluation of the technology probe kit (Study B) and Ero (Study D). (See Table 3.7). Research question 1b was divided into two sub-questions for the sake of the analysis:

- if (and how) energy-reliant and energy-managing could enable roles within meta-roles and
- if (and how) energy-reliant and energy-managing artefacts could challenge the prevailing meta-role.

To answer those two questions, I analysed the data in three steps, as detailed in the following paragraphs.

Table 3.7. *Procedures and methods for cross-study analysis for RQ 1b.*

RQ	Study	Type	Aim	Procedures & methods	Output
1b: shaping roles?	n.a.	Cross-study analysis for RQ 1b	Synthesising findings related to roles across studies	Synthesising the results from all studies, but mainly Studies B and D. Making use of activity theory and especially activity (mis)match analysis.	Knowledge about how artefacts shape roles presented in Section 5.2

Step 1. Descriptive summaries. As a first step I summarised the data (transcripts of interviews, and from Study B also photos and notes by the participants) in a descriptive manner based on recurring patterns. Examples of patterns are ways in which the prototypes were used, experienced, understood, and opinions about them. For Study D, the descriptive summaries also included data from the two questionnaires. In this way, I related the qualitative data with the quantitative to form an integrated interpretation from both types of data sources (i.e. convergent mixed methods study design (cf. Creswell, 2014).

Step 2. Activity (mis)match analysis. To deepen the understanding of how the prototypes were used, I identified recurring matches and mismatches – as explained in Figure 3.5 – that occurred as the participants integrated the prototypes into their everyday activities. Matches and mismatches relating to the different ways of using (and not using) the prototypes showed similarities with the matches and mismatches of typical activities within the three meta-roles (identified in step 5 in the cross-study analysis for research question 1a). In the activity (mis)match analysis I therefore described recurring matches and mismatches for each of the meta-roles, for Study B and for the second and third meta-roles for Study D. For Study D, I performed the activity (mis)match analysis for a typical energy-reliant activity as well as for a typical energy-managing activity.

Step 3. Inductive reasoning. Based on the descriptive summaries and the activity (mis) match analysis I answered – through inductive reasoning – whether or not (and how) energy-reliant and energy-managing artefacts could enable roles within meta-roles and/or challenge a prevailing meta-role. In Section 5.2, I present the descriptive summaries, the activity (mis)match analyses as well as answers to the two sub-questions.

Cross-study analysis – RQ 2 (Design artefacts?)

To answer research question 2 – In view of the roles householders would consider and play in energy systems, how could design of energy-reliant and energy-managing artefacts shape potential for reduced negative environmental impact? – I first compiled a collection of energy-reliant and energy-managing artefacts encountered throughout my work: in interviews with participants (primarily in Study A and Study C), through benchmarking, study visits, and (design concepts) in scientific literature. I also included the artefacts designed as part of the research in the collection, in other words the two research prototypes designed for Studies B and D. (See Table 3.8.) The artefacts in the collection were then reviewed in three steps, as detailed in the following paragraphs.

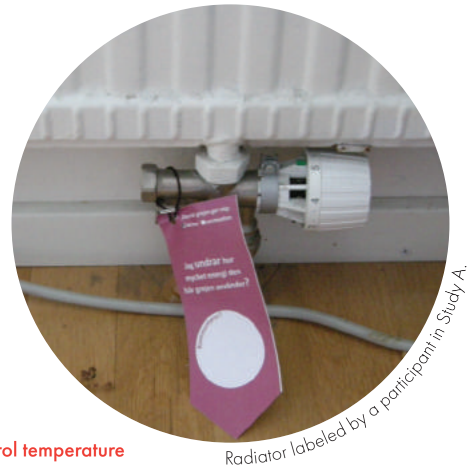
Table 3.8. *Procedures and methods for cross-study analysis for RQ 2.*

RQ	Study	Type	Aim	Procedures & methods	Output
2: what artefacts?	n.a.	Cross-study analysis for RQ 2	Synthesising findings related to roles across studies	Synthesising the results from all studies, but mainly Studies B and D. Making use of Layers of Design Making and activity theory, especially activity (mis)match analysis.	Knowledge about how to design artefacts presented in Section 5.1 and 5.3

Step 1. Artefacts for different meta-roles? If artefacts are part of shaping what roles people consider and play (cf. RQ 1b) some artefacts should 'fit' better with some meta-roles than with others. When reviewing the collection of artefacts, I therefore identified which of them fitted with which of the three meta-roles. To do so, I first identified any matches and mismatches between the artefacts and the meta-roles; artefacts that reduced interaction possibilities did not, for instance, fit with a meta-role that stresses the importance of interaction. If an artefact matched with one meta-role and mismatched with the others the artefact was considered to fit with that meta-role. As a complementary analysis, I also compared possible matches and mismatches in

potential activities that could incorporate the artefact with matches and mismatches of typical activities within the different meta-roles (see step 5 in the cross-study analysis for research question 1). If the matches and mismatches were similar, the artefact was considered to fit into that meta-role. This first step of the analysis resulted in a collection of artefacts for each meta-role, where some artefacts were considered to fit two meta-roles.

Step 2. Design strategies within meta-roles. The artefacts compiled for each meta-role were thereafter grouped based on commonalities such as whether users were supposed to notice the solution or not (first meta-role), whether they foreground energy or not (second meta-role), or whether they address energy-managing activities or not (third meta-role). These commonalities were then conceptualised as different *design strategies*, resulting in three design strategies (for the first and second meta-role) and five design strategies (for the third meta-role). To do so, I analysed the artefacts using Layers of Design to identify in what way these artefacts influence people's preconditions, see Figure 3.8. For the two prototypes' design as part of the research, describing the ideas behind them was also important so as to be able to conceptualise design strategies.



Layers of Design

Enabled activity: thermal comfort

Artefact type(s): radiator with themostatic radiator valve

Operative functions
- Operating concept: district heating + control temperature
- Practical functions: missing e.g. possibility to heat parts of bodies

Interactive functions: in practice, temperature is difficult to control + uncomfortable to reach

Communicative functions: placement of thermostatic radiator valve communicates infrequent interaction, symbols and figures are difficult to interpret

Figure 3.8. *An example of how an artefact was analysed using Layers of Design.*

Step 3. Potential strengths and weaknesses with the design strategies. Based on empirical findings from Studies A to D, I then described possible strengths and weaknesses with the design strategies in relation to reduced negative environmental impact. As the design strategies were not formally evaluated in Studies A to D, these strengths and weaknesses are not more than 'possible' in this thesis but could be explored in future work.

3.3.7 Tactics for confirming findings

Tactics for ensuring the quality of findings and conclusions were employed increasingly systematically during the course of this PhD journey. In all of the studies I have used the tactic of 'making counts' (cf. Miles et al., 2014, p. 282) to be able to identify which patterns (i.e. findings, themes, or conclusions) were more common or less common – including in relation to qualitative data. I typically first identified a pattern and then made a count to see how often the pattern occurred to verify if it was more common or less common in that particular context and with those specific participants. Although the participants in Studies A to D were not randomly sampled, keeping track of the numbers of participants, frequency of patterns and so on was a way to at least show the distribution provided by each sample. Furthermore, counting is a way to keep oneself "analytically honest" – a way to protect against bias (Miles et al., 2014, p. 282). Checking the intercoder agreement was a more systematic way of confirming patterns used in Study D (see Section 3.3.5). Discussion with co-authors, especially when writing Papers B and D, was important in order to confirm interpretations and avoid assumptions (cf. Babapour, 2019).

The participants represented in none of the studies a random sample from the site I have been studying – households in Gothenburg. The participants in Studies C and D were not even considered representative of an average household in Gothenburg as they were all living lab residents. I therefore had to rely on other methods to at least understand the level of representativeness of the samples and thus the generalisability and transferability of the results. In Studies B and C, I used standardised survey questions from the International Social Survey Programme (ISSP, 2012) to understand the participants' environmental opinions and to be able to compare the result to Swedes in general. In Study D, the participants were instead interviewed about their environmental opinions. In the two studies featuring participants from a living lab, the participants in the sensitising booklets (Study C) and in the interviews (Study D) were asked about the choice to move to a living lab, the perceived influence from the living lab, and differences compared to an 'ordinary' home to understand more about their level of representativeness. The samples in Studies C and D included half the residents at the living lab (Study C) and a majority of the living lab residents that could participate (Study D). (Only some of the residents in the living lab could participate in Study D due to technical reasons.)

Triangulation of methods and data types (e.g. qualitative and quantitative) (cf. Miles et al., 2014) was a tactic used to confirm findings in all empirical studies. Using both social practice theory and activity theory can further be seen as triangulation by theory (Miles et al., 2014), as could previous attempts to use other theories (Renström & Rahe, 2013). Studies A and C provided at least two sources of data for research question 1a and Studies B and D did likewise for research questions 1b and 2. The findings showed "meaningful parallelism across data sources" (cf. Miles et al., 2014, p. 312).

The findings, especially those in Studies C and D, are not generalisable due to the uncertainty of the participants' level of representativeness, among other factors. Rich descriptions of the contexts and the results have therefore been included to support an assessment of the findings' transferability (cf. Miles et al., 2014). Finally, in Chapter 6 the findings are compared with prior research studies as both agreement and disagreement with previous findings can clarify the other contexts to which the findings could be transferred (cf. Miles et al., 2014).

3.4 SUMMARY

This thesis relies on a pragmatic approach to research: doing what works to pave the way for more sustainable development. The research is mostly of an empirical nature with prescriptive and prospective aims rather than descriptive. However, the appended Paper X was non-empirical and relied on literature/theory-based conceptual research resulting in the Layers of Design framework.

Four empirical studies (Studies A to D) and three cross-case analyses answered the three research questions. Studies A and C were concerned with how things are and resulted in the appended Papers A and C, respectively. Studies B and D included designing of research prototypes and their evaluation, as reported in Papers B and D, respectively. The methodological approach was informed by design research and by an integrative research approach (also called a mixed methods approach). The cross-case analyses combined an inductive approach with a deductive, theory-driven approach relying on social practice theory (for RQ 1a), activity theory (for all research questions), and Layers of Design (for RQ 2). Activity theory was especially used to analyse matches and mismatches between components of everyday activities including energy-reliant and energy-managing artefacts.

Photo from Study C by Sofie Andersson.

4 ROLES IN ENERGY SYSTEMS

The previous chapter presented the methodological approached, primarily research through design and integrative research (mixed methods approach), as well as the specific procedures and methods used. This chapter presents the answer to research question 1a (see below). An overview of the answer is first presented as roles, meta-roles, and frames are explained. The roles and meta-roles are then reviewed in greater depth. Finally, these findings are revisited with social practice theory and activity theory.

RQ 1a. What roles could householders, in their everyday lives, play in district heating systems, smart energy systems, and combinations of the two?

4.1 ROLES, META-ROLES & FRAMES

The findings from Study A and Study C showed that the participants considered playing a variety of roles in relation to district heating systems and smart energy systems (including electricity and district heating); in total 16 roles were found. Some of these roles were more similar to one another than the others, one might say that some of these roles had a somewhat similar 'flavour'. As described in Section 3.3.6, the roles could, based on their 'flavour', be put into three different groups, see Figure 4.1 and Table 4.1.

These groups could be described as being held together by what I conceptualised as *meta-roles*: general roles describable as based on general principles that overarch the specific roles that the participants in Study A and Study C considered and sometimes performed, see Figure 4.2.

Table 4.1. *The themes that the 16 roles were inferred from and the three groups into which the 16 roles were put.*

Group	Theme	Role
1	Thermal comfort	Use other means
		Be unaware
	Control	Test control
		Be passive
	Understanding and awareness	Be aware on a city level
		Not use less
2	Convenience and comfort	Prioritise everyday needs
		Use 'better' artefacts
	Incentives	Maximise through information
		Use what is needed
3	Individual and societal measures	Take responsibility
		Accept societal change
	Compromises	Make compromises
	Interest and awareness	Be informed
		Be guided
	Webs of activities in more sustainable societies	Address sustainability holistically

The meta-roles could be described as also including other specific roles – with the same character as the considered roles – that households and other actors could find conceivable and sometimes also perceived, although for various reasons did not consider relevant in a given context, see Figure 4.3. Installing solar panels was for instance a role many participants found conceivable and perceived but was not considered relevant if living in a rental apartment. The meta-roles can thus also be described as *all* conceivable roles, considered (and maybe performed) as well as not considered. This description of meta-roles bears a likeness to Strömberg's term (2015, p. 40) "perceived action space" used to denote perceived and mentally activated actions. Strömberg's term "considered action space", explained as actions regarded as worthy of evaluation, is similar to the concept of considered roles.

The three meta-roles were denominated *Reception*, *Interplay*, and *Balance*. In Reception, households' meta-role is to receive standardised amounts and variants of services from the energy system in terms of heating, electricity and so on. In Interplay, households' meta-role is to use some kind of interplay with the energy system to optimise their energy services for their individual preferences, for example low cost. In Balance, finally, households' meta-role is to balance their individual preferences with what is preferable from an energy system perspective, for instance without benefits to be part of time-shifting energy use to cut peaks in demand. These meta-roles, the

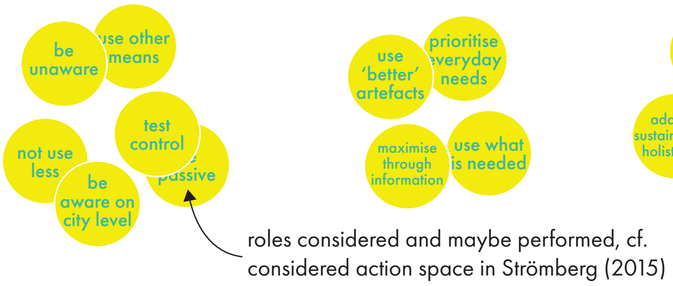


Figure 4.1. *The 16 roles considered by the participants in Studies A and C had similarities and could be put into three groups.*

Figure 4.2. *The three groups of considered roles could be described as being overarched by general meta-roles*

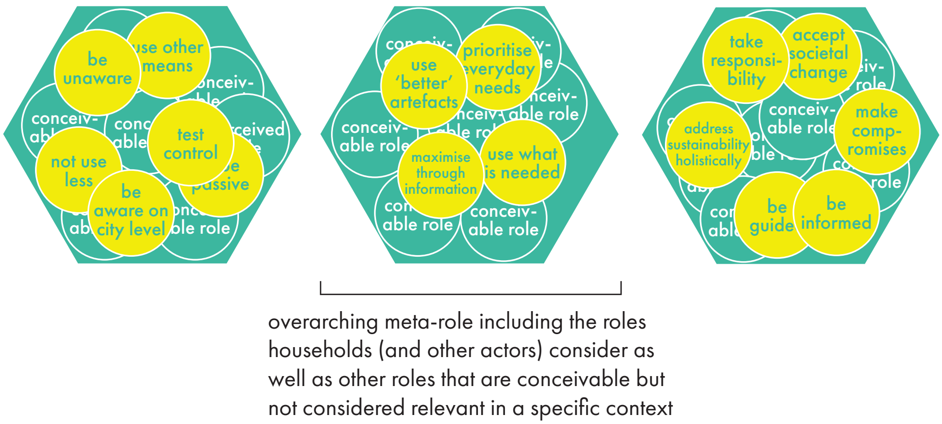


Figure 4.3. *The meta-roles also included other roles that households (and other actors) could find conceivable and sometimes perceived but did not consider relevant in a given context.*

corresponding considered roles and the empirical findings that formed the considered roles are elaborated on in Section 4.2.

Findings from Studies A and C, interviews with district heating experts at Göteborg Energi, the interviews that were part of the design process of Study D, and informal discussions with Göteborg Energi were summarised into five aspects – different immaterial and material facets of society – that *framed* the meta-roles. These aspects were:

- infrastructure,
- energy-reliant and energy-managing artefacts (including all layers defined in Layers of Design),
- business models,
- roles played and considered by other households (or peers' roles), and
- policy and regulation, see also Figure 4.4.

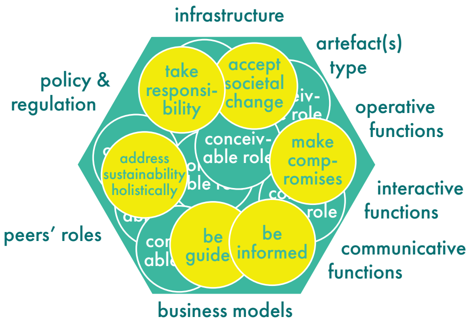


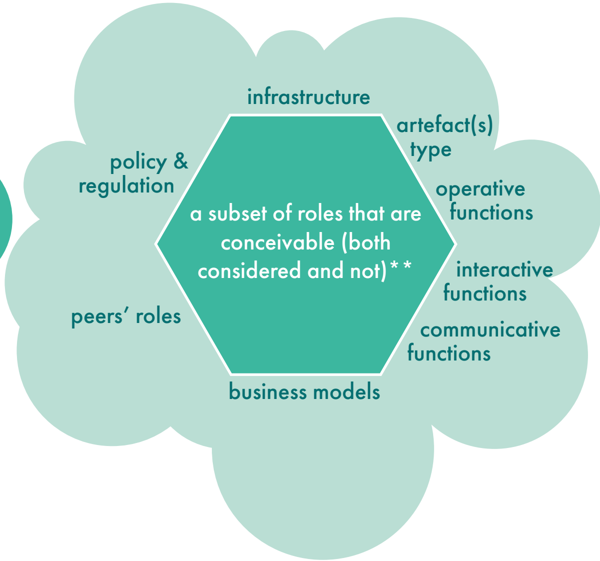
Figure 4.4. *Five aspects that frame the meta-roles. Note that artefacts are regarded as consisting of the layers described in the Layers of Design framework.*

The frame demarcates a subset of *all* conceivable roles, including considered (and maybe performed) as well as not considered roles, from a larger set of all roles that could be played, see Figure 4.5. That larger set could be described as all abstractly possible actions (cf. Strömberg, 2015, p. 39).

The aspects framed the meta-roles for households as well as the other actors in energy systems (e.g. energy companies) in different ways: all actors were more prone to perceive and consider a role enabled with the current infrastructure, in line with current policies and regulations, and facilitated by current energy-reliant and energy-managing artefacts. I also found that the interactive and communicative functions of

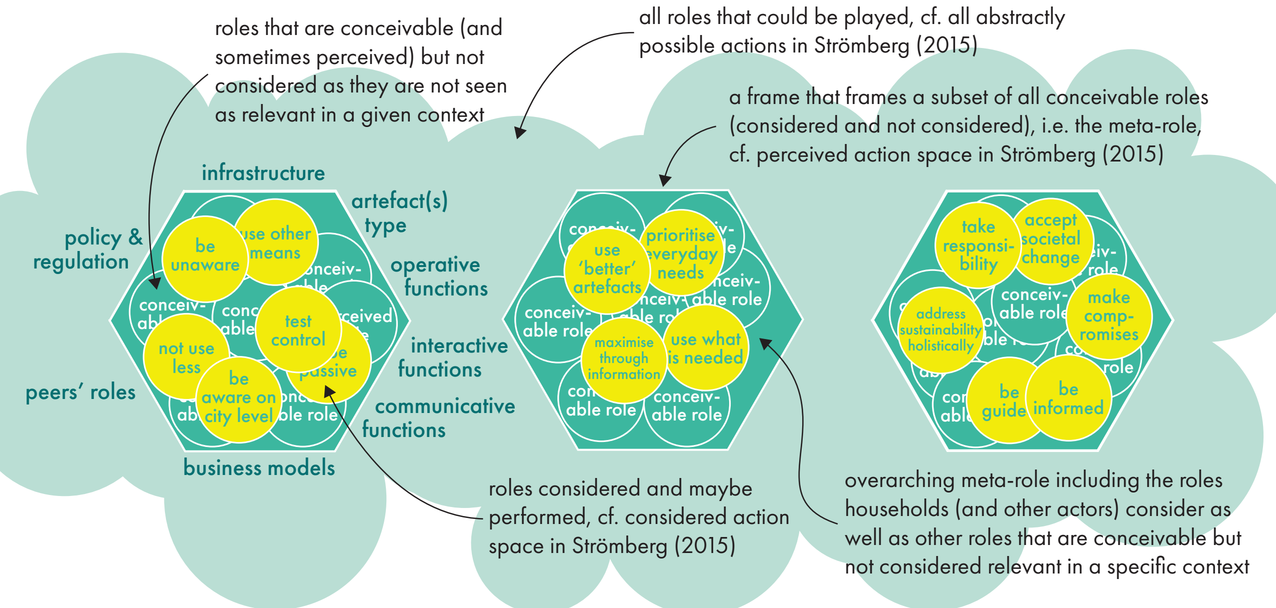
Figure 4.5 (right, top). *From the set of all roles that could be possible (left), the aspects frame a subset of roles that are assumed to be conceivable overarched by a meta-role.*

Figure 4.6 (right, bottom). *An overview of all roles that could be possible, conceivable, and considered role as well as the three meta-roles, and aspects found to frame the meta-roles.*



*cf. all abstractly possible actions in Strömberg (2015)

**cf. perceived action space in Strömberg (2015)



Reception:
receive standardised amounts and variants of services from the energy system in terms of heating, electricity etc.

Interplay:
through interplay with the energy system optimise energy services for individual preferences, e.g. low cost.

Balance:
balance their individual preferences with what is preferable from an energy system perspective

energy-reliant and energy-managing artefacts are important; if a thermostat is difficult to adjust, then that aspect served as a frame for Reception, for instance. Business models framed as what is profitable also seemed to be considered a reasonable thing to do. In addition, the roles other households considered framed as those roles were perceivable and seemed relevant.

Some of the aspects are directly shared: some infrastructure is shared where it is available and in a context in which a policy operates, it applies to all, for example. Other aspects are shared as (most) households and other actors in energy systems are aware of them, such as peer roles or what types of energy-reliant and energy-managing artefacts are available on the market. As the aspects are shared I regard the meta-roles as also being shared among the different actors of energy systems: households, energy utilities, producers of energy-reliant and energy-managing artefacts, and so on. This idea of the meta-roles as shared has a clear link to the notion that practices exist as shared entities. See Figure 4.6 for an overview of the meta-roles and related concepts.

4.2 RECEPTION, INTERPLAY & BALANCE

Withn Reception, the household's meta-role is to be a receiver of standardised services from the energy system in terms of heating and electricity, for instance. The energy system aligns with this meta-role in the sense that it is optimised to deliver a pre-defined, non-individualised service, for instance a specific and stable indoor temperature. What householders want from the service or what they think of the service is not considered important in Reception – the interesting part is how to deliver the service as efficiently and sustainably as possible. Householders are either not supposed to interact (with the system) or are not encouraged to interact with the system.

Interplay is about individualising energy services to suit individual preferences. In the Interplay meta-role, households are considered to be interested in, and are encouraged to, (in different ways) interact with the energy system to optimise energy services according to personal preferences; householders are expected to try to maximise their 'benefit' by interacting with the system. However, within Interplay, exactly what is one's 'benefit' can be understood in different ways. For some householders it is to save money, for others it is about increasing comfort or reducing one's carbon footprint. The system aligns with this meta-role by enabling and facilitating interaction, for example by enabling the choice of energy service provider and through energy feedback systems.

Households in the Balance meta-role are considered to be willing to balance their individual needs and preferences with what is appropriate from the energy system's perspective, without any significant external benefits or rewards such as lowered cost or increased comfort. This balance could be about time-shifting energy-reliant activities to cut peaks in power demand, or to think in terms of sufficiency rather than increased comfort or convenience. The Balance meta-role suggests that households could see themselves more as co-creators of the energy system.

The following section presents the 16 specific roles that householders played (Study A), could play with other preconditions (Study B), and wanted to play in future energy systems (Study C). The roles that the participants considered in relation to district heating in apartments were generally overarched by Reception and in detached houses by Interplay. The roles considered in relation to future smart energy systems were typically overarched either by Interplay or by Balance.

4.2.1 Within Reception

In Study A the participants primarily considered and performed roles overarched by the meta-role Reception. The roles were inferred from three thematic summaries covering *thermal comfort*, *control*, and *understanding and awareness*. Note that 'within Reception', or any other meta-roles, means to act within Balance.

Thermal comfort

Study A showed that householders' needs and wants in relation to indoor space heating and hot water, that is to say different services provided by district heating, vary – both from one person to another as well as from one use situation to another. Nonetheless, in Reception, district heating is intended to provide a uniform level of heating and the system is optimised for that goal. With that intention in mind, it is not surprising that in most homes in Study A the district heating was (almost) always on, aiming for a constant set point temperature, and rarely adjusted. In the differences between the aim of the system with regard to thermal comfort and the mean of a stable indoor temperature, there is a risk of sub-optimisation as thermal comfort may be achieved at different temperatures depending on what householders are doing at home, for example.

All the actions a resident can take to pursue thermal comfort can be seen as a personal heating system. Study A further showed that district heating plays a part in this personal heating system, but for most of the participants additional means are more frequently and actively used, see Figure 4.7. These findings imply that district heating in the shape of space heating was not enough for the participants in Study A to achieve thermal comfort, or that district heating did not provide thermal comfort in a satisfactory way. Personal heating systems include means for thermal comfort with different characteristics: some means are directed to different body parts and some to the whole body; some means are fast and effective while others are slow; some are energy-intensive while others are not; some use district heating and others electricity; and some also have emotional qualities.

Infrequent adjustments of the heating and additional means of achieving thermal comfort are not problems *per se* but, as discussed in Paper A, it seemed as if that may conceal the contribution of district heating in householders' pursuits of thermal comfort. In relation to thermal comfort, the participants considered and performed two different roles, often in combination, that both fitted within Reception.

- Use other means: the participants used additional means for thermal comfort more frequently and more actively – and seemed to prefer those means for thermal comfort.

- Be unaware: the participants seemed not to think so much about the contribution of district heating to their pursuit of thermal comfort.

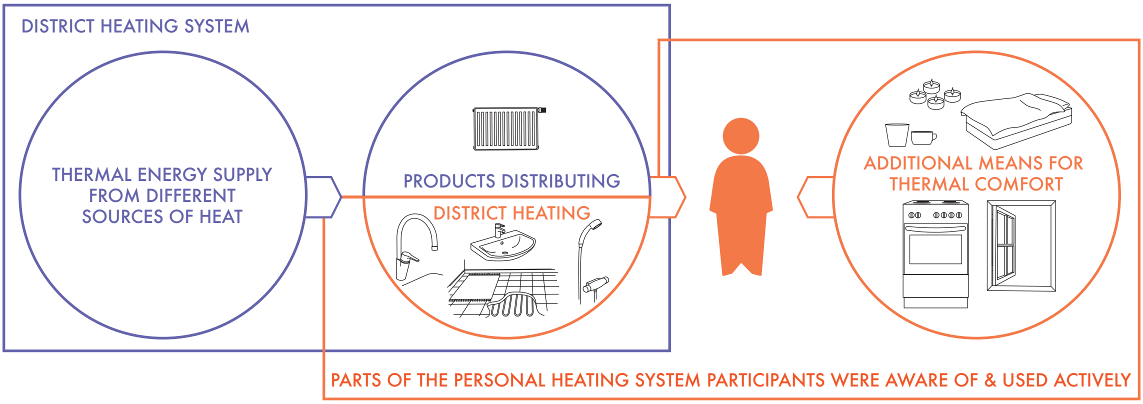


Figure 4.7. *An overview of householders' personal heating systems.*

Control

The participants in Study A were often uncertain about what, if any, control they had over the heating, about the duty of different key players, and who or what controls the temperature (although some mentioned sensors). The participants' uncertainty about their eligibility to control the system was reflected in comments, such as, "*I think they have turned the heating off now*" (participants in Study A) without being able to specify who they thought 'they' were. In addition, the participants were uncertain about the state of the heating system, resulting in questions like "*Is the heating on?*" (participants in Study A). Another example of uncertainty was described by a participant who sometimes adjusted the setting of the thermostatic radiator valves back and forth to establish if she indeed had any control. While some of the participants used these different ways of gaining an understanding and control over the system most of them did the opposite – they rarely interacted with their heating system at all. Although it was difficult to ascertain what level of control each participant actually had as that depended on the local conditions, the findings did imply that the participants lacked perceived control and that they often lacked actual control as well. Additionally, as the heating was often set at maximum, control possibilities in reality were limited. Lacking feedback about the state of the radiators and poor usability of thermostats contributed to this experience of lacking control.

The perceived lack of control over the heating discouraged some of the interviewees from lowering the indoor temperature when going away on holidays, but most interviewees said they had not considered it or simply forgot to do it. Very few participants said that they turned the radiators off when airing out even though some of them acknowledged that it was wasteful to not do so.

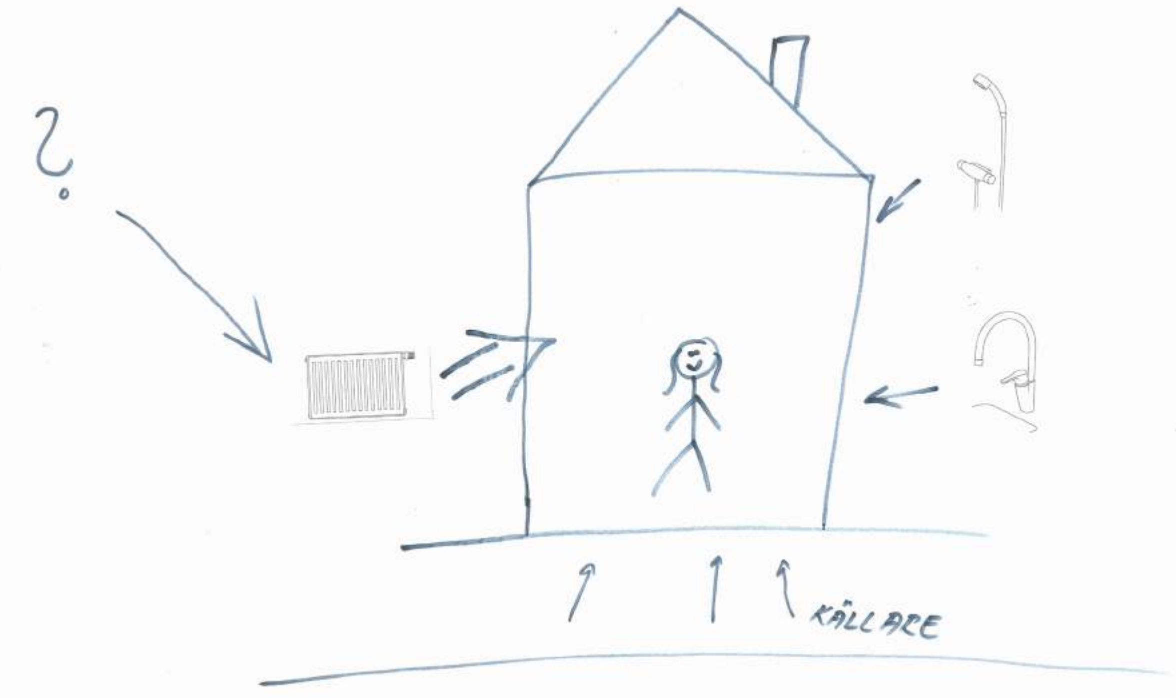
The participants experienced a lack of perceivable control over heating and they responded to that lack in different ways, representing two considered and performed roles within Reception.

- Test control: a few participants tried to test what control possibilities they had.
- Be passive: most participants became passive users, they rarely interacted with the heating system at all.

Understanding & awareness

In the interviews in Study A, 12 of the 25 participants who lived in apartments did not know if their homes were heated by district heating or nor, which is not surprising given that there are few ways of knowing if a particular space is heated by district heating. In homes with district heating, the type of heating (hydronic), radiators, thermostats, taps, and showerheads are not unique for district heating while unique parts of a heating system in a home heated with district heating – such as pipes and substation – are often located in the basement and not accessible to residents living in apartment buildings. In a home supplied with district heating, the experiences of heating and hot water supply are not necessarily different to any other thermal energy supply methods. In leasehold apartments prospective buyers are informed about their source of heating at the point of purchase and heating is usually brought up at annual leaseholder association meetings, but those meetings are not attended by everyone. There are occasionally stickers in the entrance of blocks of apartments with the anonymous acronym "FV" (short for "fjärrvärme", district heating in Swedish), but those are directed to district heating professionals. In the Reception meta-role, it seems as if it is not important if householders know that their homes are heated by district heating and they are not expected to reflect upon their consumption; as one participant put it: "*it's not top of my mind*". Despite this lack of knowledge and reflection, a majority of the interviewees in Study A had some understanding of the district heating systems in general, and of how the heat was produced. These findings suggest that the participants in Study A were more aware of district heating as a phenomenon or system in the city, in the shape of waste incineration, the physical buildings, and the underground pipes, than as a supplier of thermal comfort in their homes. In Figure 4.8 two participants have drawn their understanding of the heating systems in their homes, including their understanding of where the energy comes form.

Many of the participants in Study A regarded themselves as moderate users of heating and hot water in comparison with other people; they therefore found it difficult to curtail. Nevertheless, the participants considered it important to reduce their consumption. Environmental protection was the most frequently mentioned reason for curtailing, together with a general idea that one ought to economise, combined with an aversion to waste. For interviewees in detached houses, cost was explicitly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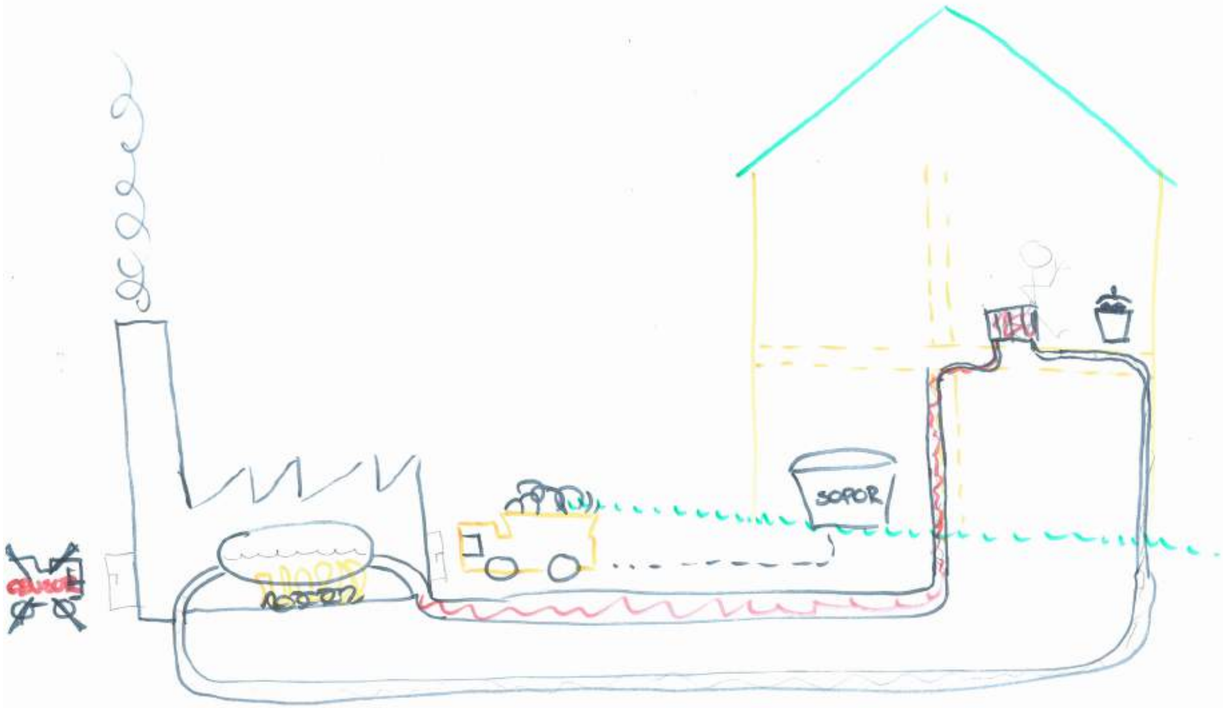
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Figure 4.8 (left). *Drawings made by two participants in Study A showing their understanding of their respective home's heating systems including where the heating comes from. Note that in the drawing at the bottom the participant included her own waste bin in the energy system as that waste will later be incinerated and brought back to her in the shape of district heating. Note also the truck with the text "censur" on it (Swedish for "censure"). In this participant's understanding, that truck delivers waste of a kind she did not want to know about or did not approve of – such as waste imported from Norway (a hot topic at the time of this research study).*

mentioned as a reason to save. However, a few interviewees did not feel it was important to reduce the consumption of heating and hot water. The fact that heating and hot water are included in the rent of apartments discouraged some interviewees from reducing their consumption, either because they would not benefit from it or because they just had not reflected on the possibility at all. The lack of feedback on their consumption contributed to this.

With regard to the home, the participants seemed to be more aware of some of the artefacts that distribute district heating than of others. They were either more aware of the objects they frequently had to interact with (e.g. taps and showers) or the things they could sense with the body, see Figure 4.7.

Regarding awareness and understanding, two different roles were identified.

- Be aware on a city level: some participants were completely unaware of district heating as a provider of heating in their homes, but aware of it as a phenomenon in the city.
- Not use less: many participants thought of themselves as moderate users of energy with few possibilities to use less.

4.2.2 Through Interplay

Roles overarched by Interplay were identified in Study A (mainly from householders living in (semi-)detached privately owned houses) and Study C. The considered roles were identified in relation to two thematic summaries: *convenience and comfort* and *incentives*.

Convenience & comfort

In the Interplay meta-role, with its more individualistic approach, it is possible to prioritise convenience and comfort; and householders are presumed to be lazy. In Study C, some participants wanted to be within the Interplay meta-role in future energy systems too: "*I don't want it to be hard or difficult to be sustainable, so I think you have to change a lot of things that won't compromise on people's laziness*". Similarly, modest changes to everyday life were preferred by some participants as, with the 'right' (sometimes not yet invented) artefacts, modest changes were thought to suffice.

Among the 35 interviewees in Study A2, ten preferred warm homes. Two of them wanted it to be as warm as possible and three wanted it to be warm enough to wear only T-shirts or shorts. On the other hand, four interviewees in Study A2 mentioned that they were not too bothered with a slightly cooler home, either because they did not spend much time at home or because they considered a warm home to be wasteful.

Prioritising a warm, cosy home or regular long, hot showers were in Interplay considered a reason to not curtail; "*I don't think too much about 'oh, have I showered too long' because for me it's my way of relaxing and I think it's ok*" (participant in Study C). The constant supply of domestic hot water from the district heating system makes it possible to shower for as long as one wants to, and, in apartments, householders usually pay indirectly for district heating – the cost is included in the rent. In Study A, the lack of feedback on consumption was considered to contribute to this experience of endless supply.

Two roles that lie within Interplay could be inferred from this summarise of findings related to convenience and comfort.

- Prioritise everyday needs: some participants saw their role as prioritising convenience, comfort, and/or other needs over energy savings.
- Use 'better' artefacts: another, similar, role was to wait for and utilise (new) artefacts with new operating concepts and other functions with modest implications for everyday life.

Incentives

In Interplay, incentives – mainly economic – were considered as a way to circumvent people's tendency to maximise their comfort or convenience: "… '*If I take a shorter shower today my grandchildren will be able to live in a world that isn't 5 degrees hotter' you don't think like that. […] Unless it is super-expensive for you to take a long shower*" (participant in Study C). Similarly, a few participants who now lived in privately owned detached houses and paid for their district heating said that they had thought "*I'm not paying for it*" when using heating or hot water in apartments in which they previously lived. On the other hand, some participants in Study A2 claimed that they would use just as much as today, since they only use what is needed.

Among the participants in Study A, more measures had been taken to reduce electricity use than reduce district heating use and saving on electricity was generally considered more important. In addition, several interviewees perceived that they had more control over their electricity use and that it was easier to reduce electricity use. Feedback on electricity consumption through the bill supported their impressions. It was considered difficult to get an overview of the effects of measures taken to reduce district heating use. For example, one participant in Study A living in a detached house was uncertain about the effects of installing triple-glazing, an investment she made to increase energy efficiency, and another participant in Study A did not perceive any effects of insulating the attic in her detached house.

The idea that feedback on energy consumption is a necessity to be able to save energy was common in Study C. A majority of the participants wanted specific and detailed information about their energy use, for instance how much each appliance uses or when choosing between alternatives. There were also participants in Study C, even though they were few in number, who had little or no interest in feedback.

The participants in the studies also discussed other types of incentives, such as different kinds of eco-labels or eco-points, competing with oneself, for instance regarding driving more fuel-efficiently, and relying on self-produced energy only (the latter two were mentioned by a householder interviewed in the design phase of Study D).

In Interplay householders are expected to maximise their benefit, where one of the benefits can be incentives. However, a couple of participants seemed resistant towards maximising their own benefits, as described in the following two identified roles.

- Maximise through information: some participants wanted to maximise the incentives from the system, mainly economic but also other, and to do that information of some sort was considered helpful. Energy feedback was often preferred. If there were no incentives, they wanted to maximise other benefits.
- Use what is needed: a few participants wanted to only use what they considered they needed and were not interested in maximising incentives or benefits.

4.2.3 Towards Balance

Primarily in Study C, the participants considered roles related to Balance. The participants' discussion could be condensed into four thematic summaries – entitled *individual and societal responses*, *compromises and convenience*, *interest and awareness*, and *webs of activities in more sustainable societies* – from which roles were inferred.

Individual & societal measures

In relation to Balance, the participants in Study C discussed both individual and societal measures to achieve an energy system with less negative environmental impact. Some participants emphasised the need for individual measures as they thought that what individuals do collectively has a significant impact and that what you do influences others. Individual measures come with individual responsibility for realising the measure, but not necessarily for deciding about what measures to take, as pointed out by one participant in Study C: *"Someone else should make sure that the energy is good and that the environment is good and everything […] someone else should take care of it [i.e. figure it out] and then I can do it."* Influencing others by showing what is possible was also part of the motivation for one of the participants interviewed in the design and development phase of Ero who wanted to go off-grid.

Other participants, primarily in Study C and in Study D, considered individual measures to be insufficient and advocated societal measures, preferably with a national or global approach, such as addressing large industries and the world's largest countries. Nonetheless, as those measures were out of the participants' control, most participants implemented what they considered to be their 'share' of individual measures as such measures were in their control; individual measures were taken to avoid feelings of resignation.

The emphasis on either individual or societal measures was interpreted as two roles within Balance.

- Take responsibility: some participants considered it to be their role to manage their use of energy in different ways as it was their way of taking responsibility for an energy future with less negative environmental impact. A couple of these participants, however, felt that it was their role to accept personal responsibility only if given the right conditions, for instance taking responsibility for doing as 'told' or if responsibility is incentivised.
- Accept societal change: other participants emphasised their role as waiting for and subsequently accepting societal responses. Individual measures were employed to avoid feelings of resignation while waiting for societal measures.

Compromises

During a session in Study C, one participant asked, "*Do we have to compromise to be sustainable?*" Another participant responded: "*I think to 'compromise', in that concept, in itself, I think it's part of sustainability*." Although not always expressed as compromises, several participants also seemed prepared to start making compromises. Some recalled phases in life when they had been making compromises, such as time-shifting laundry to the evening or night "*and it was not the end of the world, it was ok for everyone*" (participant in Study C). Similarly, participants in Study A living in detached houses with district heating said that once they had become used to how their respective heating systems worked, they accepted flaws in the systems. This position was in contrast with that of most other participants in Study A who were dissatisfied with their heating and used other means to stay warm (see Section 4.2.1). Acceptance of compromises was interpreted as one role within Balance.

- Make compromises: some of the participants saw their roles as prioritising what the energy system 'needs' over personal needs, and in that sense making compromises and accepting efforts.

Interest & awareness

In Study A, lack of information about district heating seemed to contribute to unawareness of district heating use and an understanding of having few possibilities to use less (see Section 4.2.1). In line with those findings, most participants in Study C wanted specific and detailed information about energy use and environmental impact. Such information was considered to enable the participants to think for themselves and to choose the alternative with the least negative environmental impact.

In Study C, there were also a few participants with little or no interest in information and awareness: *"I don't have to understand everything [...] if it works and is useful"* (participant in Study C). To do so, these participants would appreciate if 'someone' told them what the best alternative is. For participants in Study D, testing Ero seemed to contribute to a move towards not needing to know everything, see Figure 4.9, as they realised that more information did not necessarily lead to possibilities to act on this information.

HOW SHOULD CHANGES TOWARDS A MORE SUSTAINABLE ENERGY SYSTEM HAPPEN?

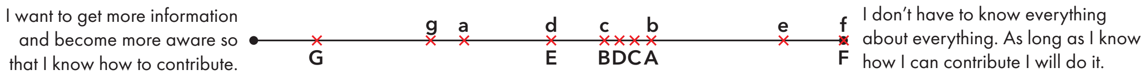


Figure 4.9. *The Study D participants' (called A to G) orientations towards one dimension in relation to energy and sustainability before (lower case, e.g. a) and after (upper case, e.g. A) evaluating Ero (see Paper D for the other dimension).*

In relation to interest and awareness, two roles found to fit within Balance were identified.

- Be informed: being informed and aware about energy was a role the majority of the participants imagined for themselves.
- Be guided: some participants saw their role as being guided and complying. Guidance could be direct, meaning being told what to do, or indirect by doing what was facilitated or incentivised.

Webs of activities in more sustainable societies

In Study C the participants found energy-reliant and energy-managing activities to be interwoven with other activities in everyday life. They did not only imagine themselves as living in a more energy-sustainable home, but included a number of different aspects: other resources (e.g. water), activities that are not directly energy-reliant (e.g. recycling, reuse, repair, and sharing), activities that are not directly energy-reliant (e.g. recycling, reuse, repair, and sharing), activities outside the home (e.g. shopping, commuting, and long-distance travel), and activities with other types of environmental impact than those related directly to energy (e.g. food and textiles). Two participants in Study B – the evaluation of the technology probe kit – seemed to also have recognised connections between everyday activities as during the evaluation of the kit they reported that they had started to recycle more. One of them specifically mentioned that she had started to think of district heating as a way of recycling heat and analogously got inspired to also contribute to waste recycling. The links between an energy system with less negative environmental impact and other aspects of sustainability were interpreted as a role found to fit within Balance.

- Address sustainability holistically: the participants did not only consider contributing to energy systems with less negative environmental impact but also considered addressing many aspects of sustainability in a more holistic manner.

4.3 THROUGH THE LENS OF SOCIAL-PRACTICE THEORY

To deepen understanding of meta-roles, I viewed the meta-roles as bundles of practices and identified what images, energy-related stuff, and types of skills made up these bundles. This analysis of Reception, Interplay, and Balance is found below.

4.3.1 Images, energy-related stuff & types of skills in Reception

In Reception, the shared *image* of the role householders should play in relation to the energy system can be described as passive and obedient. The *types of skills* needed to be passive and obedient are not directly related to the energy system, but instead are about how to deal with situations in which the energy system does not perform as intended, or as preferred. In Reception, householders need to know how to stay warm when the heating system is not providing enough warmth, or to be satisfied with the level of energy service that you receive. Householders might also need to have the skills of being disobedient, such as removing thermostatic radiator valves to boost heating or blocking ventilation to stop unwanted draughts. When it comes to *energy-related stuff*, householders generally do not need energy-managing artefacts as they are not expected – and often not allowed to – manage energy. Energy-reliant artefacts are needed, however. With such artefacts, the skills needed in Reception are not related to the energy system (such as operating artefacts in an energy-efficient manner) but related to everyday life (such as preparing a delicious meal using the artefacts).

4.3.2 Images, energy-related stuff & types of skills in Interplay

In Interplay, the shared *image* of the role householders should play in relation to the energy system can be described as one of being interested in optimising for personal preferences. Here, the *types of skills* needed are energy-related, both in terms of managing energy and operating energy-reliant artefacts in energy-efficient manner. Terms like power, energy, watt, and efficient are important to know. The energy-related skills especially concern the home since homes are sites for expressing personal preferences (such as a certain indoor temperature) and for discussing personal preferences between members of the household (such as how long and how often to shower).
In Interplay, householders also need to know how the energy system in their homes works and how their appliances function, as well as which technology is the most efficient. Another skill is to know one's personal preferences, such as low costs. Knowing how much energy costs is thus necessary. When it comes to *energy-related stuff* the efficiency of energy-reliant artefacts is important, such as what operating concept they make use of and what alternatives are available. Energy-reliant artefacts are judged on efficiency as well as on characteristics related to other aspects of everyday life. Artefacts need to perform in relation to both aspects – a low-flow shower head still needs to rinse shampoo out of the hair as efficiently as an ordinary shower head does. Energy-managing artefacts are essential in Interplay as the optimisation often relies on energy feedback from such artefacts. The more direct and precise the feedback is, the better it is.

4.3.3 Images, energy-related stuff & types of skills in Balance

In Balance, the shared *image* of the role householders should play in relation to the energy system can be described as flexible and wanting to balance personal preferences with what is preferred from the perspective of the energy system. As a result, the *types of skills* needed are related to energy use in the home and also to being able to interpret the situation in the energy system. Just as in Reception, a useful skill in Balance is to be satisfied with the level of energy service that the energy system can currently provide. Being flexible in time is also an important skill as you might not receive the level of energy service that you want when you want it. Another type of flexibility-related skill is to be able to adapt practices to what householders are told to do, for example to incorporate *energy-related stuff* that has potential for radical alterations of energy-reliant practices. Energy-managing artefacts can be important in order to be able to actively balance energy use, but instead of focusing on feedback about energy use they focus on feedback about the status of the energy system.

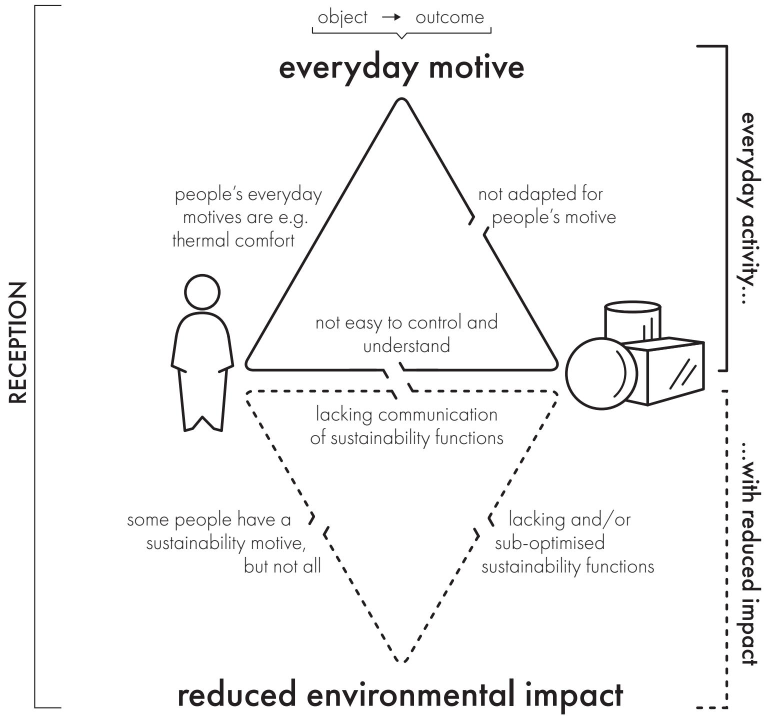
4.4 THROUGH THE LENS OF ACTIVITY THEORY

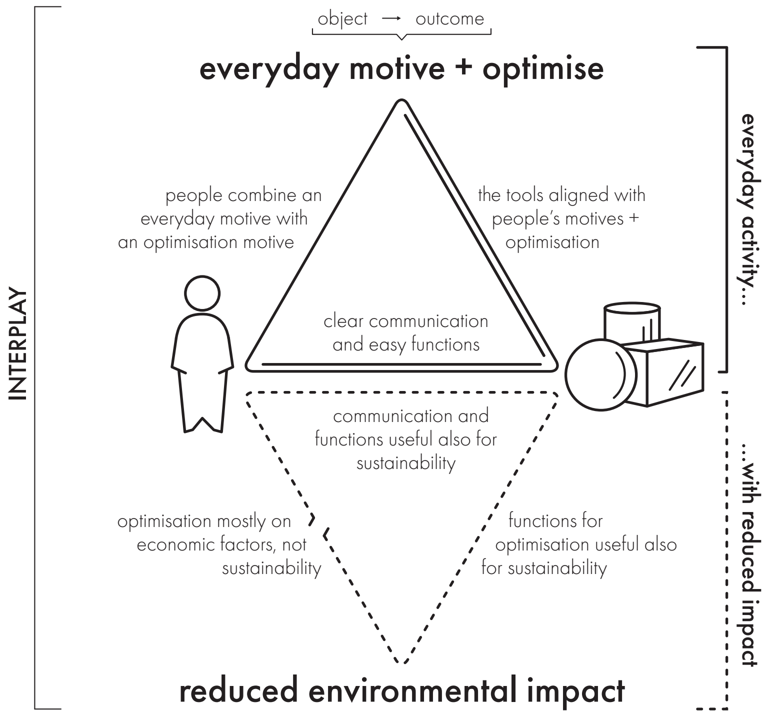
To understand the meta-roles from an activity-oriented perspective, I analysed typical energy-reliant everyday activities within the three meta-roles by identifying matches and mismatches within the activity systems. The analysis is summarised in Figure 4.10. When exemplification was needed the activity of pursuing thermal comfort is used as this activity is present both in Reception (district heating in apartments) and Interplay (district heating in detached houses). Within Balance, the typical activity is based on roles householders consider playing since in the studies in this thesis, the Balance meta-role was not found to be as common as Reception and Interplay.

When it comes to the motive of the activity, the three meta-roles differed from each other, see Figure 4.10. In Reception, there is solely an everyday motive, such as achieving thermal comfort. In Interplay, there is a combined motive of optimising the achievement of thermal comfort in some way, for example for low cost. In Balance, the everyday motive is combined with some kind of (often personally defined) constraint, such as not wanting to use fossil fuels when achieving thermal comfort.

The motive of reducing negative environmental impact from the everyday activity, which when it comes to pursuing thermal comfort could be formulated as achieving thermal comfort with less negative environmental impact, is not necessarily a motive for householders in Reception and Interplay (described as mismatches between the subject and the reduced negative environmental impact motive in Figure 4.10.). In Balance the reduced negative environmental impact motive is included through the constraint to the everyday motive, see Figure 4.10.

Regarding the (ecology of) tools in activities, in Reception they are not adapted for householders' individual activities but rather for delivering a standardised energy service (e.g. a uniform indoor temperature). For the same reason, they lack functions related to reduced negative environmental impact in relation to the *activity*; they


RECEPTION
object → outcome
everyday motive
people's everyday motives are e.g. thermal comfort
not adapted for people's motive
not easy to control and understand
lacking communication of sustainability functions
some people have a sustainability motive, but not all
lacking and/or sub-optimised sustainability functions
reduced environmental impact
everyday activity...
...with reduced impact


INTERPLAY
object → outcome
everyday motive + optimise
people combine an everyday motive with an optimisation motive
the tools aligned with people's motives + optimisation
clear communication and easy functions
communication and functions useful also for sustainability
optimisation mostly on economic factors, not sustainability
functions for optimisation useful also for sustainability
reduced environmental impact
everyday activity...
...with reduced impact

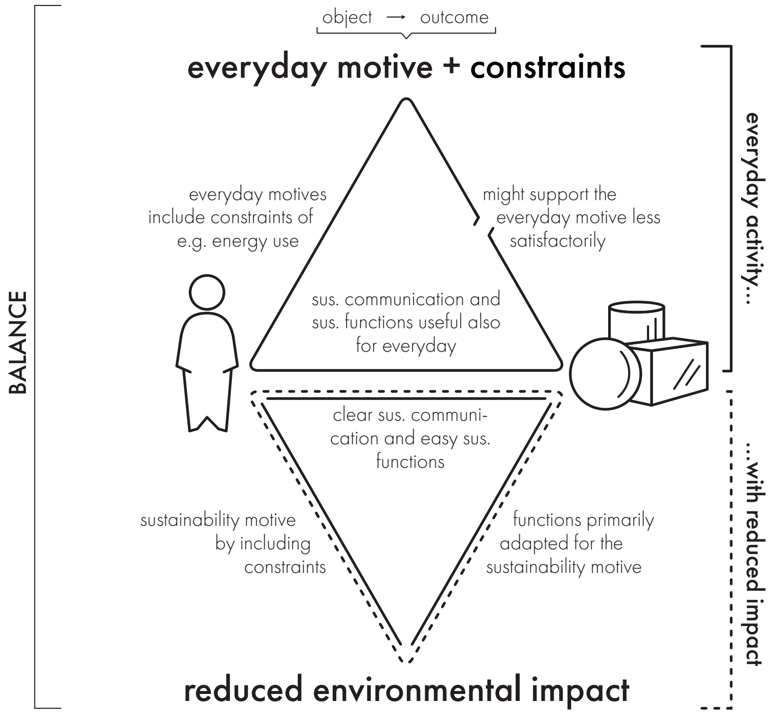


Figure 4.10. *Analysis of typical everyday activities within the three meta-roles: Reception (left, top), Interplay (left, bottom), and Balance (above).*

can be efficient in delivering the standardised energy service with reduced negative environmental impact, but that service is not necessarily what people find useful in their activities. In Interplay, the tools have functions that make them possible to individualise and the tools can therefore be adapted to match individuals' everyday motives. The functions for optimising can typically be used for lower environmental impact as well, if that is what the person wants. In Balance, the tools are typically less good at supporting the everyday motive as they are primary optimised for a reduction in negative environmental impact. One example of this is the voluntary service Heat Pledge in which householders lower their indoor temperature (less good support for achieving thermal comfort) at peaks in demand (better support for reduced negative environmental impact) (cf. Uusitalo, 2016, pp., see also Section 1.3.3).

Reception stands out when it comes to the connections between householders and (ecologies of) tools. In Reception tools are typically not designed with the intention to be easy to understand and use – they are designed with the intention to deliver a standardised energy service. Both radiators and thermostats are examples of tools with significant usability flaws that are designed to deliver a standardised energy service in the shape of a uniform indoor temperature. In Interplay, the communication is clear and the functions are easy to access and use for the everyday motive and this generally also contributes to clarity and usefulness for reducing negative environmental impact. The opposite applies for Balance: clear and useful functions for reducing negative environmental impact contribute to clarity and ease of use for the everyday motive.

When activities change, as described in Section 2.1.2, tools intended to solve contradictions in and between activities also give rise to new contradictions, in a dialectic manner. Within a meta-role, these developments do not significantly influence the motives. The everyday motive of staying thermally comfortable, for instance, remains the same. A significant change in the motive, such as when the motive of optimising or constraining is added to the everyday motive as in Figure 4.10, is what I describe as a new meta-role. A significant change in an everyday motive can be understood as an objectification of un-objectified needs: a tool that enables householders to combine an everyday motive with for instance balancing also enables such a wish to become an activity. In the energy sector, one important part of the tools in the ecologies of artefacts is infrastructure. This makes it more difficult to radically change artefact ecology, and maybe to also objectify un-objectified needs.

4.5 SUMMARY

The energy-reliant and energy-managing activities that the participants primarily in Study A and C engaged in or considered engaging in, the way these activities were performed, and what energy system-related outcomes the participants intended with these activities, were interpreted as different roles for households in the energy system. Sixteen roles were identified and, based on similarities and differences, they could be put into three groups. Then, three meta-roles were conceptualised as overarching the specific roles in each group. The meta-roles – Reception, Interplay, and Balance – include these considered roles as well as other roles assumed to be conceivable and sometimes perceived but not considered relevant in a given context. In Reception, households receive standardised amounts and variants of services from the energy system in terms of heating, electricity and so on. In Interplay, households optimise their energy services for their individual preferences, often low cost, through some kind of interplay with the energy system. In Balance, finally, households consider their individual preferences in relation to what is preferable from an energy system perspective and adapt to the energy situation. The meta-roles can be understood as framed by five different aspects: a frame that frames a subset of conceivable and considered roles (i.e. the meta-role) in a set of all roles that it is possible to play. One of these aspects was energy-reliant and energy-managing artefacts, including all their layers as outlined in the Layers of Design framework.

The meta-roles can further be understood as bundles of interrelated practices that share an image of the household in relation to the energy system, share similar skills, and incorporate similar types of energy-reliant and energy-managing stuff. In Reception, households are seen as passive and obedient, in Interplay as interested in optimising for personal preferences, and in Balance as flexible and willing to support the energy system, for instance.

Activity theory can be used to describe how motives differ between the meta-roles. In Reception, motives are typically not related to energy and reduced negative environmental impact. In Interplay, motives are related to optimisation both in relation to everyday parameters such as thermal comfort and also reduced cost or negative environmental impact. In Balance, reduced negative environmental impact follows from introducing (often personally defined) constraints to the motive, such as avoiding the use of fossil fuels.

Photo from Study B. Photo by Anneli Selvefors.

Photo from Study D. Photo by Marcus Folino.

5 DESIGNING FOR PARTICIPATION

Three meta-roles – Reception, Interplay, and Balance – were introduced and explained in the previous chapter. This chapter describes how artefacts shape what roles households consider and perform and how the design of artefacts shapes the potential for reduced negative environmental impact.

As outlined in Section 3.2.1, research through design is concerned with creating prototypes intended for use in generating knowledge. The prototypes created in this thesis work generated three forms of knowledge: (i) what can be designed, (ii) how to design, and (iii) how artefacts contribute to shaping everyday life interpreted as strategies for design. Section 5.1 presents the first two forms of knowledge generated. Section 5.2 presents how artefacts shape roles, the third form of knowledge, and Section 5.3 introduces strategies for design, which is also the third form of knowledge.

5.1 IDEAS, CONCEPTS & RESEARCH PROTOTYPES

The process of designing and prototyping the technology probe kit (see the following Section 5.1.1) and Ero (see the subsequent Section 5.1.2) as parts of Study B and Study D demonstrated ideas for how energy-reliant and energy-managing artefacts can shape the potential for reduced negative environmental impact (cf. RQ 2).

RQ 2. In view of the roles householders consider and play in energy systems, how could design of energy-reliant and energy-managing artefacts shape the potential for reduced negative environmental impact?

5.1.1 Portable person heating

Following the review and reasoning of what roles artefacts can play in research through design by Stappers and Giaccardi (2017), the technology probe kit can be understood as having demonstrated a possibility to expand the ecology of artefacts used for thermal comfort, and this is therefore one set of the insights derived from the design process. However, in agreement with Stappers and Giaccardi (2017), the technology probe kit did not tell its story on its own. The ideas behind it are a necessary framing of the kit and they are therefore explained in the following section. The fact that the technology probe kit demonstrated a possibility is however neither abstract nor generalisable (Höök et al., 2015; Stappers & Giaccardi, 2017). Nevertheless, the design process did also result in insights that could be generalised and used in future design work, as will be outlined in the following sections.

Ideas & concepts for portable person heating

The design ideas that were developed into a research prototype were based on two opportunities. First, apartments with district heating are most efficiently heated either by providing a stable indoor temperature (Fredriksen & Werner, 2013) or by providing a temperature that varies to avoid peaks in power demand (Kensby, 2015). Residents, on the other hand, often have shifting desires for heating depending on their level of physical activity and use of heat-producing artefacts (e.g. the oven), for instance (as found in Study A). To address this incompatibility one opportunity was for person heating to complement space heating. The second opportunity was to make better use of available heat sources in the home, with inspiration from what participants in Study A already did. Making better use of available heat sources in a home corresponds conceptually to the way district heating systems profit from cities' available heat sources.

These two opportunities combined resulted in the concept of portable person heating devices that can be heated via available heat sources in the home or with thermal energy from the district heating system. Four additional important requirements were identified:

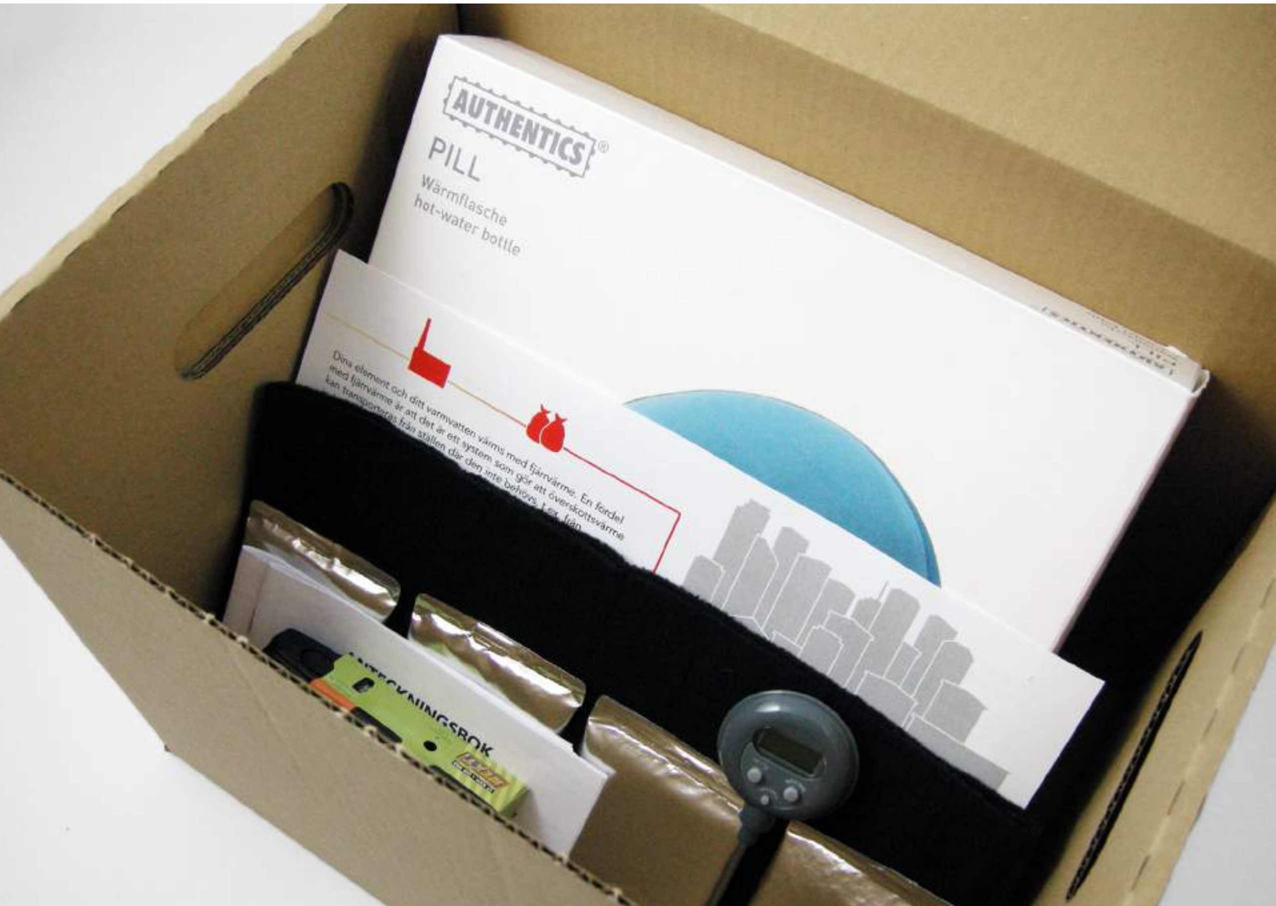
- enable people to quickly avoid thermal discomfort, yet be temporary as thermal comfort can change quickly;
- conveniently heat parts of the body, since thermal discomfort does not necessarily concern the whole body (as found in Study A), yet preferably be large enough to warm someone who is uncomfortably cold all over;
- always be ready for use, without preparation, for convenience and speed (see also Kuijer & de Jong, 2012); and
- be warm enough for people to experience a warming sensation directly, similar to the feedback people experience when touching radiators to see if they are working (as found in Study A).

The concept is an example of a design for alternative ways of doing (see Section 2.2.1) and an attempt to mediate the activity of staying thermally comfortable in a different way with potential for less energy use and increased comfort. In terms of Layers of Design, the concept represents a new type of artefact in the activity of staying thermally comfortable for many people as hot water bottles or wheat pillows are not commonly used (as found in Study A). The concept further addresses aspects of sustainability *within* existing energy-reliant activities. It does not enable any new energy-managing activities. The idea of using available heat sources in the home (including those heated with district heating) and to thus 'move' heat in the home is a new type of operating concept. The concept further relies on an existing ecology of artefacts: the district heating system, the energy system in the home, radiators, and other energy-reliant artefacts that produce surplus heat.

A technology probe kit – research prototype(s) for portable person heating

To make it possible to use simple, flexible, and adaptable technology (as suggested for technology probes (Hutchinson et al., 2003)) without alterations to existing infrastructure, the technology probe kit included both heating pads and hot water bottles, see Figure 5.1. The heating pads were made of phase change material that stores and releases high amounts of heat over a narrow temperature range (Mondal, 2008). The pads could be heated on different sources of excess heat in a home, depending on the specific conditions in each apartment. To help find suitable heat sources for the heating pads, the participants received a thermometer (which is also one way of exploring a home's microclimate (cf. Gaver et al., 2013). A hot water bottle was included in case the participants lacked useful heating spots. Participants were instructed to use hot tap water as this is heated with district heating.

Figure 5.1. *The content of the technology probe kit (photo by Anneli Selvefors).*



The kit further included an information sheet briefly describing what district heating is and how the heating devices worked, as well as explaining how using sources of excess heat in the home correspond conceptually to the way a district heating system uses available heat sources in the city. The participants also received material for self-documentation. The details of the technology probe kit can be found in Paper B.

(Some) insights from designing the technology probe kit

One potentially generalisable insight from designing the technology probe kit was that when designing for alternative ways of doing it is important to be aware of which experiences and qualities are important in the activity for which one is designing. For the technology probe kit this meant that qualities such as cosiness and physical comfort were important, as was the provision of warmth. As the heating pads had a metallic feel and sharp edges, I therefore had to make a cosy fleece cover.

The technology prototype kit added artefacts to the ecology of artefacts used in the energy-reliant activity of staying thermally comfortable. The characteristics and functions of the existing artefacts are important, and these characteristics may vary. When prototyping and experimenting with the technology probe kit I found that the surface temperature of radiators varied. As a consequence, the heating pads could be heated on the radiators in some homes while participants in other homes had to rely other sources of heating. The hot water bottle was an alternative for homes without any suitable heat sources for the heating pads.

In a prototype, all the ideas behind it need to be present simultaneously. This means that the prototype also demonstrates how the ideas could (and should not) fit together. In the technology probe kit, one requirement was that the personal heating devices should be warm enough for people to experience a warming sensation directly as a way of obtaining thermal feedback. When building the prototype, I found that it was difficult to obtain that sensation and at the same time not risk causing burn injuries in long-term use. This insight may also be useful in similar design prototypes.

Through the prototyping process I also realised the difficulties in communicating parts of the framing with the design, and this also holds true for other design prototypes. It turned out to be very difficult to express via the prototype how the use of excess heat in the home to warm up personal heating devices corresponds to the way a district heating system makes use of excess heat in a city. In the end, this link was instead explicitly explained in an information sheet.

5.1.2 New ways of organising energy use

Just as for the technology probe kit, the final prototype designed for Study D demonstrated new possibilities (cf. Stappers & Giaccardi, 2017); the prototype demonstrated new possibilities for energy-managing artefacts as well as possibilities for seeing energy-reliant activities through the lens of the status of the energy system. The prototype also represented possible future directions as it was based on ideas of what the future energy system could be like. However, the framing of the concept (cf. Stappers & Giaccardi, 2017) is needed to spotlight their meaningful features. Such insights were contextual, 'situated' (cf. Höök et al., 2015), and concrete – and not generalisable. The design process did also result in more generalisable insights, as will be presented in the following sections, just as the evaluation did (see Sections 5.2 and 5.3).

As mentioned, the final Ero prototype was based on a conceptual prototype, the Activity Organizer. The overarching principles and functions are the same, but Ero was adapted to the specific evaluation site: a living lab.

Ideas for new ways of organising energy use

When the prototypes were designed, it already mattered *when* energy was used (Kensby, 2015). With an increase in intermittent sources of renewable energy, it will matter even more. One of the fundamental ideas with the porotypes was therefore that everyday activities could be organised in relation to the status of the energy system, similarly to the way activities are organised in relation to time. A function called the energy threshold, a momentary power limit, was created to relate a household's energy-reliant activities to the status of the energy system, where status is understood as peaks and non-peaks in energy supply from different sources of energy.

Study A and Study C showed that people were to some degree interested in the energy system and especially in what sources of energy are used in the system (such as wind, solar, nuclear, fossil, and waste incineration). The energy threshold therefore shows when there is plenty of energy and when there is a shortage of energy from the source that the users prefer. The threshold was individual for each user and changed over time depending on availability. If users stayed below their energy thresholds it meant that they were using energy at a time when there was plenty of their preferred type of energy.

One idea for making the prototypes useful for organising energy-reliant activities was to enable control of energy-reliant artefacts through them and to provide energy supply forecasts. The prototypes were designed to make it possible to start, stop, and schedule both start and stop of energy-reliant artefacts. They were also designed to make it as convenient to schedule a postponed start or stop as it was to start or stop an artefact immediately. Moreover, the idea was to not add more actions to energy-reliant activities but to instead enrich the action of starting, stopping, and scheduling appliances by providing information about the energy situation (in terms of the energy threshold). The prototypes were thus intended to become part of the ecologies of artefacts used in energy-reliant activities (cf. address aspects of sustainability *within* everyday activities, Section 2.2.1). By doing so, they were intended to stay relevant by being used in existing everyday activities – and not only when users explicitly wanted to manage energy, that is to say new energy-managing activities. The prototypes were nevertheless designed to be useful also for energy-managing activities and provided energy use and energy supply feedback to be used in such activities. One energy-managing activity was introduced through Ero: to choose preferred sources or carbon dioxide intensity of energy, and this stated preference was then used to calculate the energy thresholds. Through the energy thresholds, energy-managing activities could influence energy-reliant activities.

Both prototypes were further based on the idea that the status of the energy system could be a lens through which all connected appliances in a smart home could be viewed. At the time of development there were few all-encompassing platforms for smart homes and 'platform fatigue' was an issue – with people getting tired of using different platforms for different connected appliances. The prototypes were envisioned to be able to control all energy-reliant appliances.

Ero – a research prototype featuring new ways of organising energy use

The Ero prototype was realised on an app for tablets connected to databases with energy forecasts and near real-time energy use reported from sensors in the living lab. Through the app separate smart plugs could be controlled, but for practical reasons not all power outlets could be equipped with smart plugs. The app had different functions, as detailed below.

The residents in the living lab had access to both private areas and shared areas and energy thresholds were therefore calculated for district heating and electricity in both areas. The energy thresholds were calculated as detailed below.

$$\textit{Energy threshold}_{\textit{electricity}} = \textit{Average momentary electricity use} \times \left(\frac{\textit{Current share of preferred energy}_{\textit{electricity}}}{\textit{Yearly average share of preferred energy}_{\textit{electricity}}}\right)^2$$

$$\textit{Energy threshold}_{\textit{district heating}} = \textit{Average momentary district heating use present month} \times \left(\frac{\textit{(Current outdoor temperature+30)}}{\textit{(Coldest temperature this day+30)}}\right)^1 \times \left(\frac{\textit{Current share of preferred energy}_{\textit{district heating}}}{\textit{Yearly average share of preferred energy}_{\textit{district heating}}}\right)^1$$

The energy thresholds were calculated based on temperature and energy forecasts with hourly intervals. The energy threshold for one day was calculated during the preceding evening as energy forecasts became available. The participants used the app to set what sources or characteristics of energy they preferred. They either selected preferred sources of electricity (solar, wind, hydro, nuclear, and fossil) and district heating (renewable, recycled, and fossil) or set the maximum preferred carbon dioxide intensity, see Figure 5.2.

The app's home screen showed current electricity and district heating use in relation to the energy thresholds for the selected living space. Energy use surpassing the energy threshold was marked in red. The lower half of the home screen showed energy use per sensor, see Figure 5.3, and access to the smart plugs connected to (most) electric

Figure 5.2. *Users of Ero can set their personal preferences of energy sources or carbon dioxide (CO_2) intensity in the app (excerpt from the manual given to the participants in Study D).*

sensors was controlled through this list. These are called controllable sensors in the figure.

In-depth electricity and district heating screens showed momentary energy use (in terms of electricity and district heating, respectively) and previous energy use in relation to the energy thresholds of the current day, see Figure 5.4. The graph also showed a forecast of the energy threshold so that users could see when during the current day the energy threshold was high and low, in other words when there was plentiful or a shortage of energy with the users' preferred characteristics.

Ero also presented the availability of different sources of energy for electricity and district heating. This information was available for the current day and was based on forecasts, see Figure 5.5.

(Some) insights from designing the Activity Organizer and Ero

One insight generated through designing and prototyping the Activity Organizer and Ero was that if an artefact is to be used in both energy-reliant and energy-managing activities it needs to have two facets: one simpler facet for energy-reliant activities and one more complex facet for managing energy. The Activity Organizer had a screen for managing energy and a simpler interface intended for a smart watch as well as a separate status unit that only showed current energy use in relation to the status of the energy system, based on the energy threshold. In Ero, the two facets were both available in the app, the simpler facet was the home screen and the more complex facet featured the other screens mentioned earlier. This insight could be generalised to design of other artefacts intended to be part of both energy-reliant and energy-managing activities.

Another insight from the design process that it was possible to generalise was that measuring energy use in terms of watts and power is one way of presenting the information, but when doing so it will visually be difficult to distinguish anything other than heating as this (at least in the winter in Sweden) is a large part of a home's energy use. On the home screen in Ero, energy use was therefore not visualised in absolute terms (e.g. watts) but in relation to the energy threshold.

Figure 5.3 *The home screen of the Ero app (excerpt from the manual given to the participants in Study D).*

Figure 5.4. *Electricity (left) and district heating (right) screens in the Ero app (excerpt from the manual given to the participants in Study D).*


energy threshold (grey line) for your room or common space
you can open, close, and schedule activities for sensors also from here
here the use of electricty (blue area) went over the energy threshold (grey line)
electricity used right now in your room or common space
get to this screen by clicking here
MY ROOM
COMMON SPACE
200 W
160 W
120 W
80 W
40 W
10:00
12:00
14:00
16:00
18:00
20:00
6 h
12 h
24 h
not scheduled
Sensor - [4590]
0 W
Sensor - [4591]
0 W
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ero
Electricity

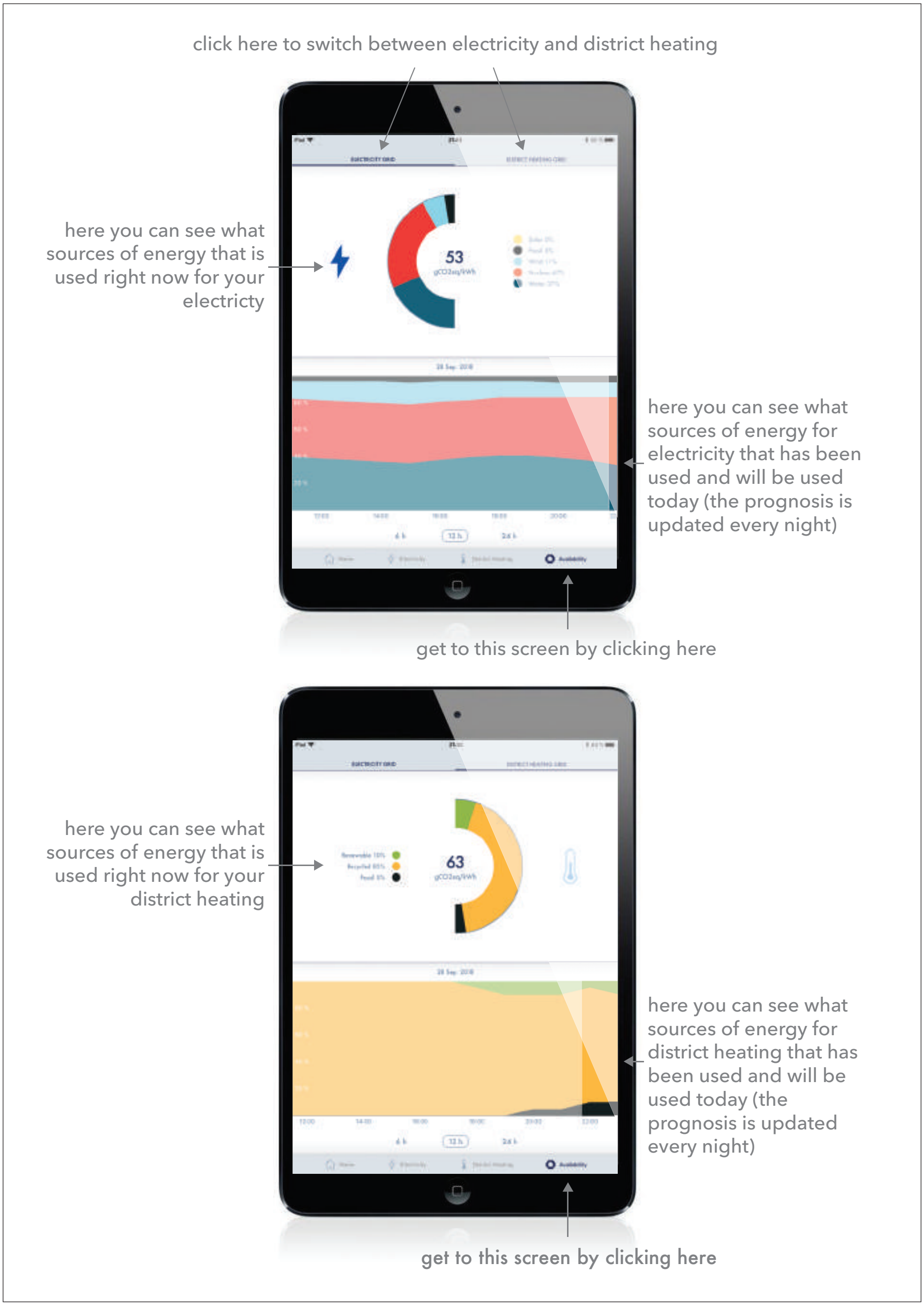


Figure 5.5. *Availability screen for electricity and district heating (excerpt from the manual given to the participants in Study D).*

5.2 ENABLING ROLES/CHALLENGING META-ROLES

Findings from the evaluations of the technology probe kit (Study B) and Ero (Study D) were used to answer research question 1b, see below. In the following section 5.2.1 and 5.2.2 findings from the two studies are presented, followed by concluding remarks (5.2.3) that summarises the answer to this research question.

RQ 1b. How do energy-reliant and energy-managing artefacts shape what roles householders consider and perform?

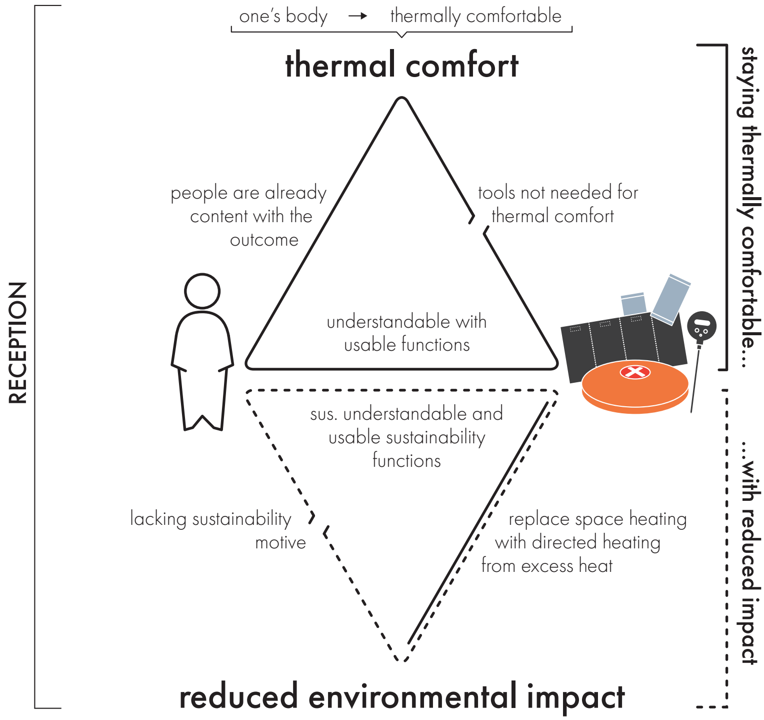
5.2.1 Enabling & challenging character of the technology probe kit

At the time of Study B, district heating in apartments was, and still is, within Reception. The technology probe kit (Study B) challenged this meta-role as it instead suggested roles for the participants within Interplay and Balance. The flexible devices for person heating in the technology probe kit provided more possibilities for thermal comfort with little energy use. In this way, the technology probe kit provided the participants with means to get more benefits out of the district heating system and thus fitted within Interplay. However, there were some characteristics of the technology probe kit that fitted better within Balance. First, the participants were asked spend time and effort on reusing heat when they heated up the devices. Secondly, in the information sheet the participants were also asked to consider lowering their heating, without getting anything in return, which is also a way of compromising.

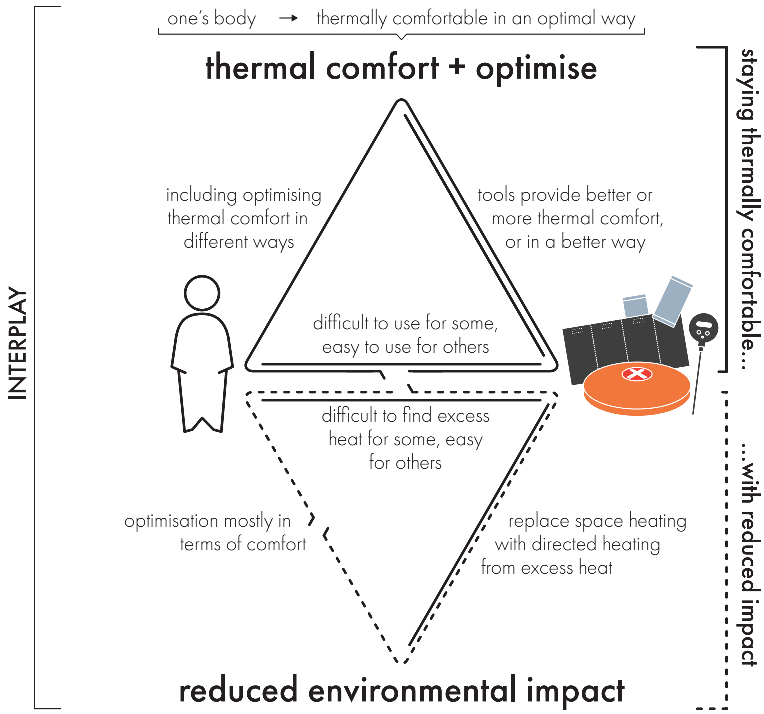
The participants in Study B responded to the technology probe kit in ways that could be understood in relation to the three meta-roles, see the analysis in Figure 5.6. First, some participants did not use the heating devices to any extent and the reason was that they had not felt cold. They saw the heating devices as tools for thermal comfort only and the participants did not, for instance, experiment with the heating devices merely for the sake of it. This focus on thermal comfort fits well within Reception in which householders are only supposed to be interested in the result of the energy service to which they are entitled.

Secondly, some of the participants in Study B used the heating devices to increase the thermal comfort benefits of the district heating system in ways that fit better within Interplay. These participants used the heating devices to supplement unsatisfactory space heating, as a better alternative to space heating, as a better alternative to other additional means for thermal comfort, or when they were freezing outdoors. Some participants thought that the heating devices in the technology probe kit had positive characteristics (e.g. fun to use) beyond the support of thermal comfort, indicating that other types of benefits were also perceived.

Several participants – depending for instance on how the radiators worked (see Paper B) – did however find it difficult, inconvenient, and time-consuming to use



RECEPTION
one's body → thermally comfortable
thermal comfort
people are already content with the outcome
tools not needed for thermal comfort
understandable with usable functions
sus. understandable and usable sustainability functions
lacking sustainability motive
replace space heating with directed heating from excess heat
reduced environmental impact
staying thermally comfortable...
...with reduced impact



INTERPLAY
one's body → thermally comfortable in an optimal way
thermal comfort + optimise
including optimising thermal comfort in different ways
tools provide better or more thermal comfort, or in a better way
difficult to use for some, easy to use for others
difficult to find excess heat for some, easy for others
optimisation mostly in terms of comfort
replace space heating with directed heating from excess heat
reduced environmental impact
staying thermally comfortable...
...with reduced impact

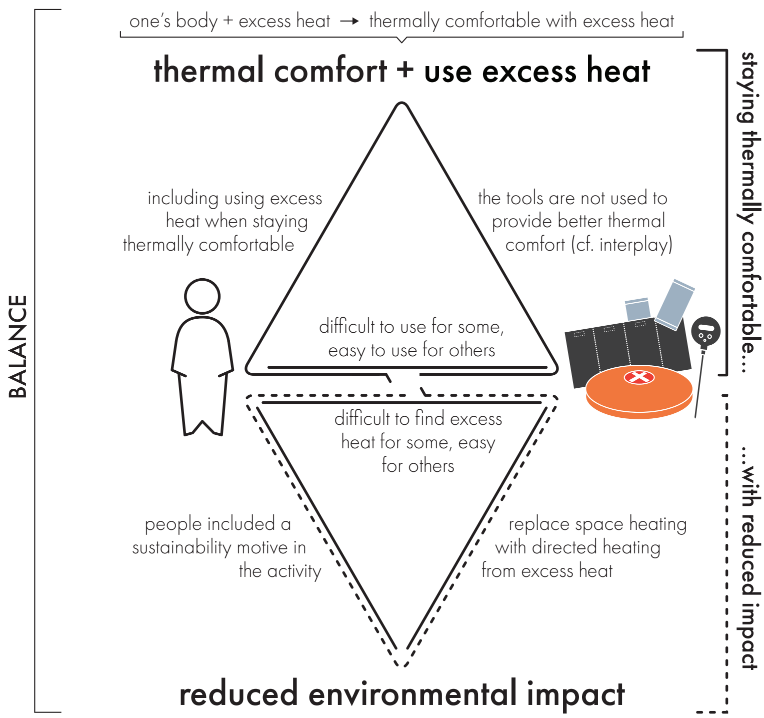


Figure 5.6. *Three different ways of including the items from the technology probe kit into the activity of maintaining thermal comfort. The three different ways fit with the three meta-roles Reception (left, top), Interplay (left, bottom), and Balance (above).*

the heating devices. Despite this, the participants used the heating devices and as a result some of them increased their awareness of different sources of excess heat in the home and wanted to make sure that heat produced in different places in the home was not wasted. One interpretation is that they had added the motive of using excess heat in the home to their activity of achieving thermal comfort, see Figure 5.6. That altered motive resulted in new actions (such as lowering heating and airing faster), new or pronounced strategies and plans for efficient home heating and waste recycling, increased awareness of heat sources in the home, and ideas for the board of the leaseholder association. These changes implied compromises without benefits, either that householders would have to make an effort themselves (e.g. making sure that no excess heat is wasted or airing faster) or that they would get less thermal comfort (e.g. lowering the heating or suggesting to the board to gradually decrease the heating). These changes therefore indicate that the participants changed from acting as within Reception or Interplay to acting within Balance.

In Study B, the technology probe kit thus seemed to challenge the participants to instead of acting as if they were within Reception acting in Interplay or Balance. Within the meta-roles, the technology probe kit seemed to enable roles resulting in reduced negative energy-related environmental impact, including actions such as use of excess heat to increase thermal comfort in Interplay or to turn down the heating in Balance. For some participants the thermal comfort activity was mediated in a different way through the technology probe kit (i.e. with heating devices instead of radiators) while others altered goals (e.g. made use of excess heat in the home) and motives (e.g. instead of thermal comfort only, the motive turned to thermal comfort through use of excess heat) of their activities. For some, the technology probe kit gave rise to increased interest in other, related, activities (e.g. waste recycling).

5.2.2 Enabling & challenging features of Ero

The reader is reminded that Ero was developed before the synthesis resulting in three meta-roles described in Chapter 4. Ero was therefore not designed to explicitly enable more roles with less negative environmental impact within Interplay, nor to explicitly challenge participants to instead act as within Balance. Just like with the technology probe kit, Ero did however have both enabling and challenging features. One of the features that enabled reduced negative energy-related environmental impact within Interplay was to provide feedback on the household's energy use which suggested that energy use can be optimised and that the way to optimise it is through detailed information (see 4.2.2, paragraph Incentives). Another characteristic was the focus on the household's own energy demand, which suggests optimising in relation to own preferences and to not think too much about other aspects of energy. As it is possible to control energy-reliant appliances through Ero – in that sense Ero is similar to smart home systems on the market – it adheres to the idea that people are lazy, and that life should be convenient and preferably become even more convenient.

Some of the features of Ero, on the other hand, challenged Interplay. First, one of the main ideas with Ero was to reconnect energy demand and supply through the energy threshold, described earlier. The intention was to enable users to shift energy-reliant activities to times when there was plenty of their preferred energy. This time-shifting could have been automated, for instance through smart plugs that operate at off-peak hours, but with Ero users had to actively time-shift either by scheduling smart plugs in the home or by time-shifting energy-reliant activities. It requires effort both to schedule smart plugs and to time-shift activities. In this way, Ero expected householders to be prepared to make such an effort. In addition, this effort is not economically incentivised or gamified – which it typically would have been in Interplay. Choosing a preferable energy source can also be a way of at least being able to share opinions relevant for societal responses through Ero – something considered relevant in Balance (see Section 4.2.3).

The participants in Study D responded to Ero in ways that could be understood in relation to both Interplay and Balance, see the activity (mis)match analysis in Figure 5.7, for both energy-reliant and energy-managing activities. None of the participants used Ero extensively and the reason mentioned was that the participants, in their view, did not use much energy and had few energy-reliant appliances (see also Paper D); mismatches in energy-reliant activities especially related to Balance in Figure

5.7. They therefore did not have much energy use to optimise. In both Interplay and Balance, relating private energy use to energy supply created a mismatch between participants and reduced negative environmental impact for energy-reliant activities, see Figure 5.7. The context of evaluation (a living lab with single-person households living in a small area with few energy-reliant appliances) seemed to influence not only how Ero was used but also how Ero was perceived.

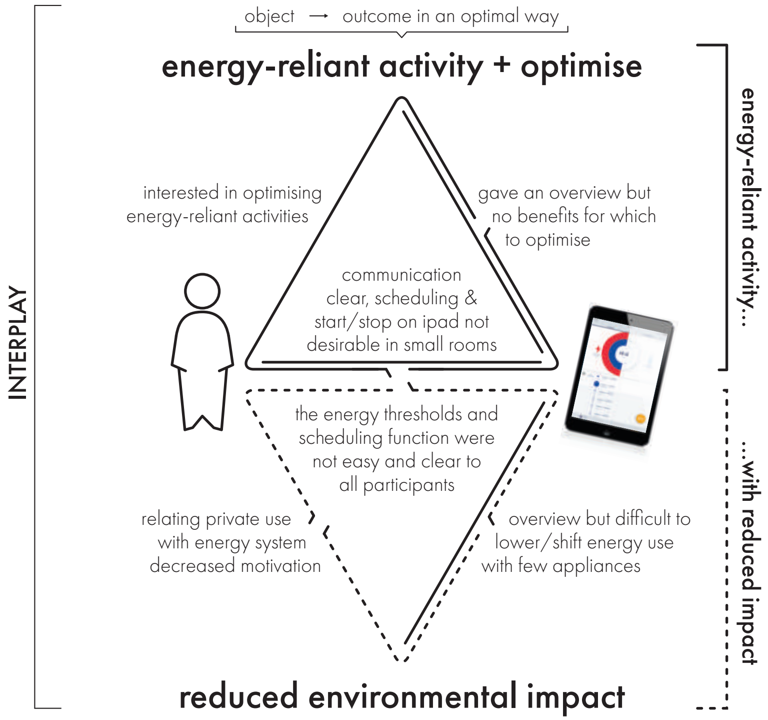
Balance suggests other possibilities than only influence through how and when to use energy, and what energy-reliant and energy-managing artefacts to use. In the questionnaire, it was possible to see that after testing Ero some participants were more interested in other ways of influencing the energy system too, such as actively taking part in local production of renewable energy (see Paper D). (Note that this change in rating is not statistically significant, possibly due to the limited number of participants.) However, Ero did not offer any support in these other ways of influencing, indicated as a tool-object mismatch for energy-managing activities related to Balance in Figure 5.7. One could say that Ero challenged Interplay for some participants, but did not enable reduced negative energy-related environmental impact within Balance.

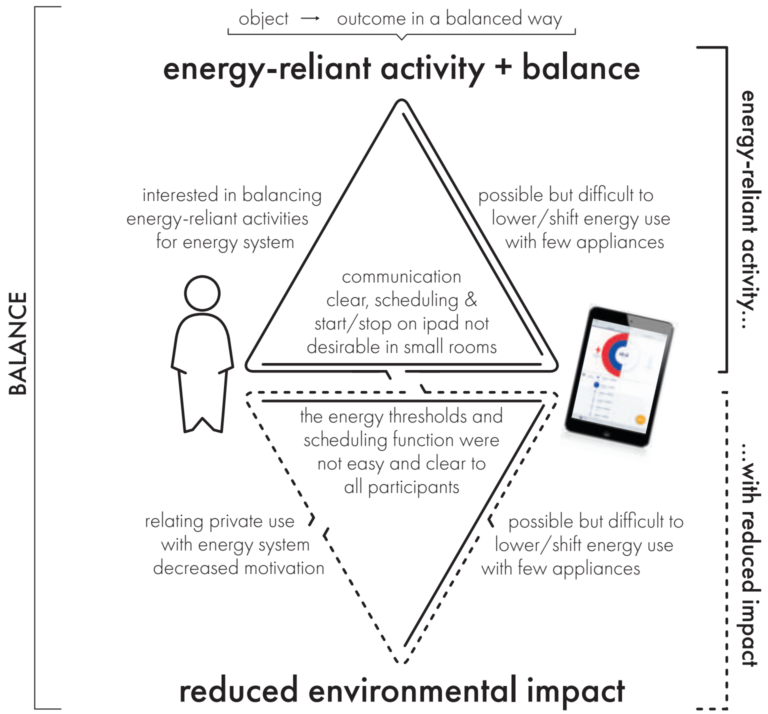
One of the features of Ero could however both challenge Interplay and mediate roles with reduced negative energy-related environmental impact within Balance if it was improved. The idea of an energy threshold was appreciated by most participants, although the personal energy threshold in the evaluation did not always function in a satisfactory way. Four of the participants wanted a more prominent energy threshold, either by being reminded of the threshold during energy-reliant activities or by power outlets being turned off in accordance with the status of the energy system.

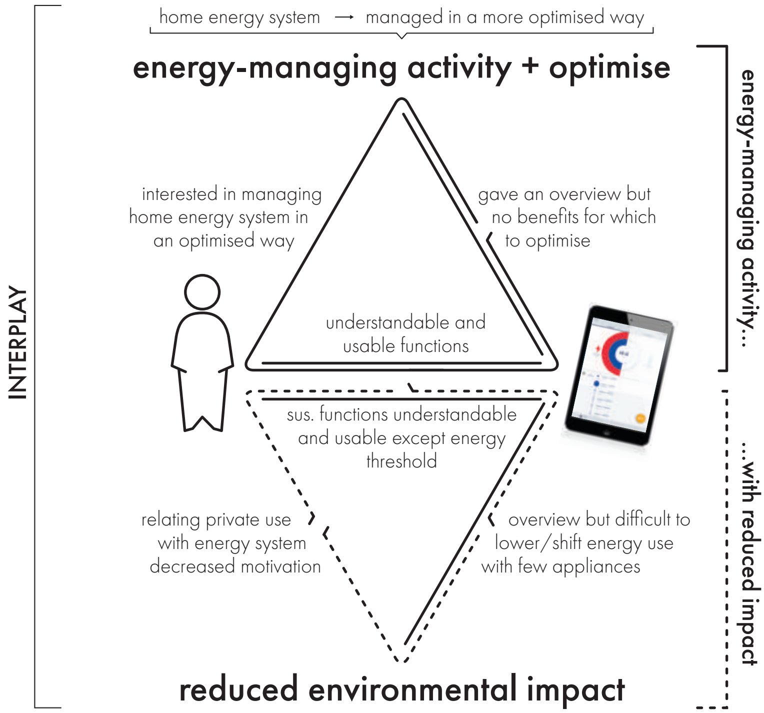
On the other hand, some of the criticism directed at Ero indicated that the participants understood the prototype in relation to Interplay, see mismatches in Figure 5.7. For instance, the participants wanted possibilities to automate time-shifting and scheduling, gamification, opportunities to compare their performance with peers, and overall more information in terms of both feedback on energy use (especially more historic feedback) and information on what sources of energy were used historically. This interest in more information seemed to be related to a wish for some kind of general but effortless awareness, that is to say general awareness about energy that does not influence activities.

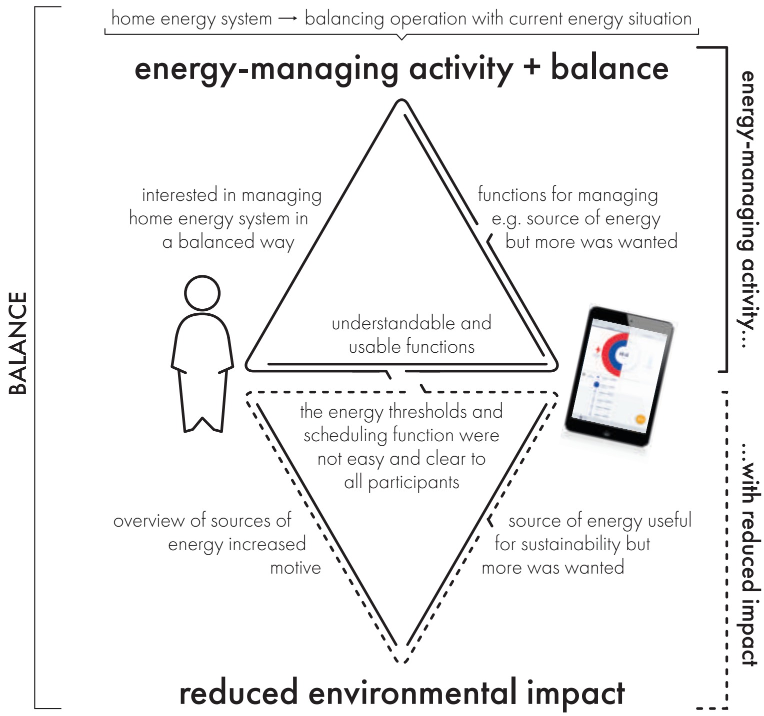
Finally, most of the participants reported that they would not have used Ero differently if they had gained economically from energy flexibility, and the result of the questionnaire suggests that economic incentives were not regarded as very important before Ero. Ero can therefore be said to support interest in reduced negative energy-related environmental impact beyond what is economically rational in a way that fits within Balance. It should be noted though that the living lab residents paid indirectly

Figure 5.7 (following spread). *Examples of matches and mismatches of Ero in energy-reliant activities (left) and energy-managing activities (right), in both Interplay (top) and Balance (bottom).*


INTERPLAY
object → outcome in an optimal way
energy-reliant activity + optimise
interested in optimising energy-reliant activities
gave an overview but no benefits for which to optimise
communication clear, scheduling & start/stop on ipad not desirable in small rooms
the energy thresholds and scheduling function were not easy and clear to all participants
relating private use with energy system decreased motivation
overview but difficult to lower/shift energy use with few appliances
reduced environmental impact
energy-reliant activity...
...with reduced impact


BALANCE
object → outcome in a balanced way
energy-reliant activity + balance
interested in balancing energy-reliant activities for energy system
possible but difficult to lower/shift energy use with few appliances
communication clear, scheduling & start/stop on ipad not desirable in small rooms
the energy thresholds and scheduling function were not easy and clear to all participants
relating private use with energy system decreased motivation
possible but difficult to lower/shift energy use with few appliances
reduced environmental impact
energy-reliant activity...
...with reduced impact


INTERPLAY
home energy system → managed in a more optimised way
energy-managing activity + optimise
interested in managing home energy system in an optimised way
gave an overview but no benefits for which to optimise
understandable and usable functions
sus. functions understandable and usable except energy threshold
relating private use with energy system decreased motivation
overview but difficult to lower/shift energy use with few appliances
reduced environmental impact
energy-managing activity...
...with reduced impact


BALANCE
home energy system → balancing operation with current energy situation
energy-managing activity + balance
interested in managing home energy system in a balanced way
functions for managing e.g. source of energy but more was wanted
understandable and usable functions
the energy thresholds and scheduling function were not easy and clear to all participants
overview of sources of energy increased motive
source of energy useful for sustainability but more was wanted
reduced environmental impact
energy-managing activity...
...with reduced impact

for energy use as it was included in their rents. It is difficult to say if economic incentives would have become important if, for instance, the participants paid directly for charging an electric car, for instance.

5.2.3 Can roles be enabled & meta-roles challenged?

To sum up, findings from Studies B and D, outlined above, indicated that both energy-reliant and energy-managing artefacts shape what roles households consider and perform by either (i) enabling reduced negative energy-related environmental impact within meta-roles or (ii) challenging a meta-role by suggesting acting as within another meta-role. The former can be described as reducing mismatches in considered and performed roles/ecologies of activities or by mediating conceivable but perhaps not considered roles/ecologies of activities. The latter can be described as incorporating a new motive into existing activities.

Study B suggested that new energy-reliant artefacts in the ecology of tools used in energy-reliant activities could influence the participants' actions, goals, motives, and interest in other activities. New energy-reliant artefacts thus supported reduced negative energy-related environmental impact within meta-roles, and the incorporation of a new motive into existing activities, see Figure 5.6, indicated a shift in meta-role for some participants – from Reception to Interplay or Balance. Findings from Study D indicated that energy-managing artefacts can also challenge a meta-role, or at least support an already ongoing process of challenging a meta-role among the participants. Nonetheless, findings from both Studies B and D suggested that this was not the case for all participants; for some the new artefacts reproduced the current meta-role. Why that is will be reflected upon in the discussion.

Findings from Study D indicated that energy-managing tools can challenge the current meta-role, in this case Interplay, without properly enabling reduced negative energy-related environmental impact in the suggested meta-role, in other words Balance. When this happened, it seemed as if the energy-managing artefact became irrelevant after the meta-role had been challenged. Artefacts that challenge a meta-role should, for continued relevance, therefore also support reduced negative energy-related environmental impact within the meta-role that they suggest.

5.3 DESIGNING FOR REDUCED ENVIRONMENTAL IMPACT

Studies B and D suggested that it could possible to design energy-reliant tools and energy-manging tools that, first, support reduced negative energy-related environmental impact within meta-roles and, second, either reproduce or challenge meta-roles. Below I suggest how to support reduced negative energy-related environmental impact within Reception (Section 5.3.1), Interplay (Section 5.3.2), and Balance (Section 5.3.3) by proposing design strategies for both energy-reliant and energy-managing artefacts and thereby providing an answer to research question 2.

These strategies are inferred by analysing energy-reliant and energy-managing artefacts encountered throughout my thesis work (in interviews with participants, through benchmarking, study visits, and in scientific literature) and designed as parts of Study B and Study D. These artefacts were considered to fit within one or more meta-roles, and design strategies were inferred from commonalities between all artefacts considered to fit within one meta-role (see Section 3.3.6 for details).

RQ 2. In view of the roles householders consider and play in energy systems, how could design of energy-reliant and energy-managing artefacts shape the potential for reduced negative environmental impact?

5.3.1 Strategies for reduced environmental impact within Reception

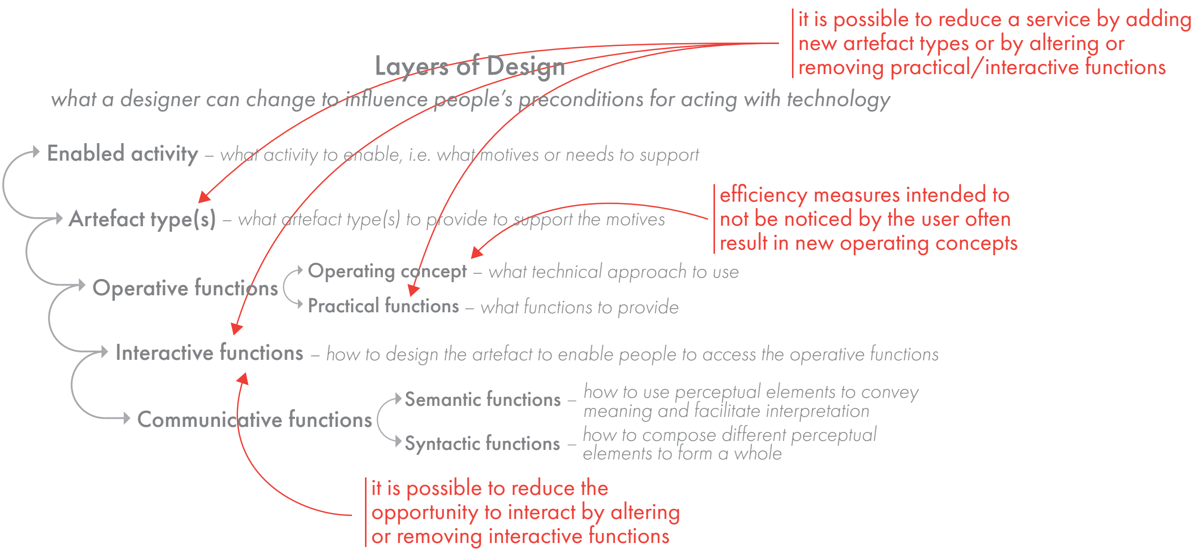
Within Reception, reduced negative energy-related environmental impact is usually about providing the service in a more efficient way and sometimes about reducing the service. An example of the former is that district heating is constantly being developed to deliver the same service in a more efficient way, according to district heating experts interviewed as a part of the design process in Study B. There is an entire organisation which constantly ensures that the cheapest heat sources with the least negative environmental impact available are used. District heating can thus be seen as "*innovation flowing in pipes*" (district heating expert in Study B). Another example is to use apartment buildings as temporary thermal energy storage units by deliberately varying the indoor temperature and in this way reducing the daily heat load variation, in other words shaving peaks in power demand (Kensby, 2015). When this solution was tested, a temperature variation of +/- 0.5°C was used so that residents would not notice any deviations from the standard temperature (Kensby, 2015). A new artefact type or a new operating concept can be introduced to increase efficiency. District cooling was an example of a new artefact type and white goods powered by district heating were examples of a new operating concept when introduced (Zinko, 2006). It is noteworthy that in innovations understood as designed for the Reception meta-role typically were designed so that users would not notice any difference compared with products powered by electricity. In this meta-role design is used to *background* energy. Many innovations in efficiency in the reception meta-role are thus not noticeable in homes (e.g. the limited temperature variation in the tests using apartment buildings as temporary thermal energy storage units (Kensby, 2015)). The heating and hot water are delivered in the same way, through the same products and giving the same experience, independent of the innovations. It makes sense, as households in Reception are not assumed to be interested in anything other than receiving the energy service. Efficiency can also be improved by controlling the service at the point of use. Thermostatic radiator valves increased the efficiency of heating through use of automation and automatic on/off switches were used for lighting. Automatic functions fit within Reception as they do not rely on user interest or active participation.

In Reception, it is considered more important to control the service than to allow users to have control over the service. The design is therefore made to reduce the number of touchpoints or options for users.

Finally, reduced negative energy-related environmental impact in Reception can also be about reducing the service, such as reducing the heating or installing low-flow shower heads. As found in Study A, such reductions can result in both energy-efficient and inefficient workarounds, such as wrapping oneself in blankets and showering to stay warm or showering longer to compensate for the reduced flow in the showerhead.

To sum up, within Reception, designing for reduced negative energy-related environmental impact typically includes *efficiency measures intended to not be noticed by the user* and if that is not possible the efficiency measures could *reduce the opportunity for users to interact* to ensure efficiency. Measures to reduce negative energy-related environmental impact are sometimes about *reducing the service* and that can result in energy-efficient workarounds, but this cannot be guaranteed. These strategies appear on different layers in Layers of Design, see Figure 5.8.

Figure 5.8. *Design strategies for reduced negative energy-related environmental impact within Reception related to Layers of Design.*



5.3.2 Strategies for reduced environmental impact within Interplay

Within Interplay, the artefacts in the collection aimed at making reduced negative energy-related environmental impact into a win-win situation. What a householder 'wins' is often economic benefits, but there are also other types of benefits (such as fun to use in Study B). In this way, a reduction of negative energy-related environmental impact is coupled with goals or motives related to other activities in everyday life, such as managing a household's budget. Other examples of 'wins' include different kinds of eco-points (discussed for instance by participants in Study C) or winning energy-related competitions that could be enabled by gamifying designs (as some participants in Studies C and D wanted). Feedback on energy use was a common way to make economic win-win solutions possible. The energy bill has historically been the primary source of feedback, backed up later by real-time feedback relying on smart technologies. With instant feedback on energy use comes also a wish to have instant control over energy-using devices. More and more smart energy technologies allow for this, such as the energy management system Green IT Homes studied as part of the benchmark of Study D (read more about Green IT Homes in IMCG, 2012). One problem however is that although these types of solutions may enable householders to think of managing energy in other activities, such as in the activity of managing the household's budget, it seems as if they are less good at altering the goals and motives of the energy-reliant activity. Green IT Homes, for instance, showed energy costs and allowed for some control over the heating, but the control was not fine-tuned enough to actually enable householders to adapt the heating to the characteristics of the different rooms in the homes, such as a cooler bedroom, a warmer bathroom, and a non-heated guest room (as pointed out by one of the interviewees in Study D that tested Green IT Homes). The findings from Study D also showed the difficulty for tools with both energy-reliant and energy-managing features to actually become integrated into energy-reliant activities in everyday life. Although Ero could be used to start, stop, and schedule energy-reliant appliances that was not the way Ero was mainly used. Instead, most of the participants used it only in energy-managing activities.

Another approach within Interplay is to employ efficient solutions to be able to provide additional benefits (as opposed to Reception where efficient solutions are used to increase efficiency only). One example of this is a private house in Gothenburg renovated with assistance from Göteborg Energi among others (Zinko, 2006). In the house, district heating was used for as many energy-reliant appliances as possible. As the appliances were more energy efficient, appliances that increased the "quality of life" (Zinko, 2006, p. 42) could be added without increasing the negative environmental impact. A heated atrium, an outdoor hot tub, and a heated driveway were examples of such appliances.

The technology probe kit in Study B also made use of the idea of efficiency as a means of providing more benefits. The heating devices were intended to be heated with excess heat and intended be a better (i.e. faster and more flexible) alternative to space heating or to supplement space heating when this was insufficient. The heating devices were a new type of artefact in the artefact ecology used to achieve thermal comfort, while feedback represented practical function and district heating powered appliances as equipped with new operating concepts. The technology probe kit did, as mentioned, require effort from the user, and that feature fits better within Balance.

Ero, and other solutions, *foreground* energy and typically the energy use of smaller units, such as one household's energy use. In Ero, energy is foregrounded through energy feedback. In addition, the sources of energy that were used were also shown, and thus foregrounded. When this foregrounding result in some kind of 'effortless awareness' (highlighted also in Section 5.2.2 above) it did not challenge the Interplay meta-role. Yet, for some of the participants in Study D, foregrounding the status of the energy system (instead of a household's energy use) seemed to challenge Interplay and instead suggested acting as within Balance (although not enabling reduced negative energy-related environmental impact within Balance, as pointed out in Section 5.2.2).

To sum up, within Interplay, designs encourage reduced negative energy-related environmental impact by *coupling impact reduction to other motives and goals in life*, for instance saving money, by *providing more benefits but in an energy-efficient way* (providing more with less), or by *foregrounding energy*. These three strategies were found to relate to different layers in Layers of Design, see Figure 5.9

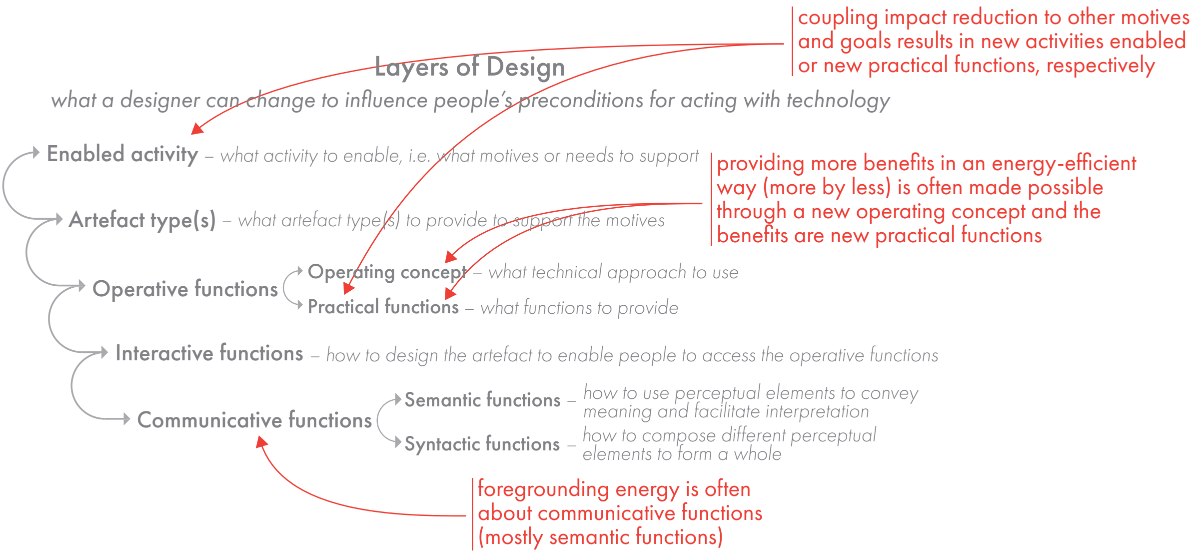


Figure 5.9. *Design strategies for reduced negative energy-related environmental impact within Interplay related to Layers of Design.*

5.3.3 Strategies for reduced environmental impact aimed at Balance

In the empirical studies, Balance was found to be an uncommon meta-role. The few products and concepts that I encountered fitted within Balance, and some of the features of the prototypes designed in Study B and Study D gave rise to five design strategies that could be suitable for Balance. But, as these strategies were uncommon they were also less verified. These strategies are related to different layers in Layers of Design, see Figure 5.10.

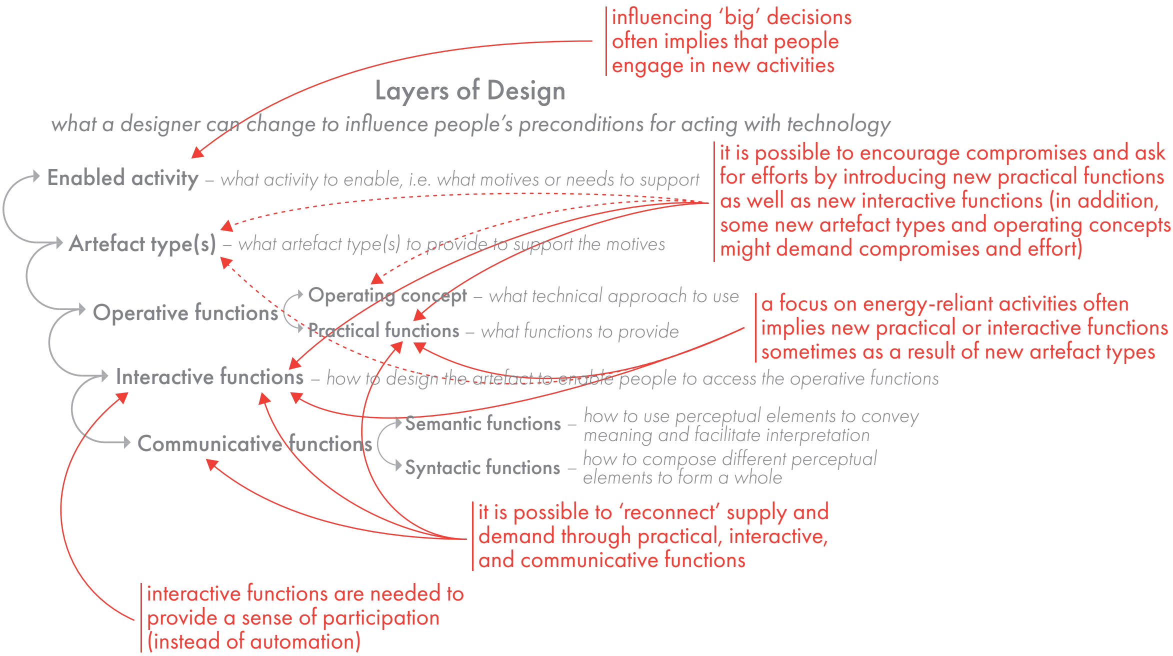


Figure 5.10. *Suggested design strategies for reduced negative energy-related environmental impact within Balance related to Layers of Design.*

Encourage compromises & ask for efforts

In both the technology probe kit and Ero, householders were expected to make efforts (finding and using excess heat/schedule energy use on a separate device) and to make compromises in relation to their energy use (lower the heating/to use energy at certain times of the day) without any explicit benefits, such as economic incentives or eco-points. The Heat Pledge service by Finnish energy utility Helen Oy (Helen Ltd., n.d.; Uusitalo, 2016) also expected householders to make the effort of lowering their heating and to accept the lowered heating (see Section 1.3.3 for a description of Heat Pledge). In Study A and Study D some participants mentioned similar wishes. One of the participants testing the home energy management system Green IT Homes (described in IMCG, 2012) interviewed in the design phase for Study D wanted to be able to match his heat demand with supply just to contribute to peak shaving, although in the current business model this would cost him more than not doing it. He explained why he wanted this by saying "*it feels good to get rid of some watts*". One suggestion for reducing negative energy-related environmental impact in Balance is therefore to use design to encourage compromises and ask for efforts. In Study B, this strategy seemed to not only fit in Balance but also to challenge Reception and Interplay for some participants.

The result from Study D showed mixed results in relation to the types of compromises and efforts that were required. The participants generally wanted time-shifting to become easier and automation was suggested as one way of achieving this. The hassle of scheduling appliances on a daily basis was not considered worth it. In Ero, it was not always easy to see when the best time for using energy was (a flaw in the design) and this may also have contributed to the wish for automation. In that sense, Ero did not give clear instructions which, based on findings from Study C, seemed to be important when suggesting compromises and asking for efforts. Instructions should make it clear that people are asked to contribute, but also that responsibility for the change is shared between the instructor and the 'doer'. In Ero, the energy thresholds were attempts to provide clear instructions, and for some participants they seemed to work as intended: *"[…] I know that I will have to charge the phone or the computer or something, so I have checked when is the best time to do it and accordingly scheduled it for then"* (participant in Study D).

Reconnect energy supply & demand

Sources of energy, that is to say one aspect of energy supply, seemed to be important for some participants in Study A and most of the participants in Study C. Regarding district heating, the majority of participants in Study A were aware of sources of district heating and district heating plants as phenomena in the city but less as a provider of heating in their homes (see Section 4.2.1); they did not connect supply (district heating) with demand (their use of heating). In Study C sources of electricity were primarily discussed. Some of the participants were either for or against specific sources of energy, nuclear power for instance, but in the participants' discussions this aspect of supply was not connected to discussions regarding demand. One of the district heating experts interviewed in Study B pointed out that one unique feature of district heating was endless, constant supply of heating and hot tap water, and the same holds for electricity. Even though convenient, this endless supply might not support an understanding of supply and demand as *connected* in the same way as sources of energy obtained as pre-defined, finite 'amounts' stored in proximity to where the energy is used (camping gas cylinders and wood, for example), as discussed by a participant in Study D or a local energy supply, as discussed by the participant interviewed in Study D who wanted to go off-grid. In everyday life, this latter participant made the connection between local energy supply and demand by always keeping track of whether energy was saved into an energy storage unit or extracted from this storage unit.

In Ero, the energy thresholds were an attempt to make a connection between supply from a sizable energy system's supply and local demand. Findings from Study D showed that a majority of the participants reported becoming more aware of the energy supply system in terms of when and how energy is produced. However, in combination with energy use feedback this awareness seemed to undermine interest in time-shifting energy use as, in their own words, they used very little energy. Instead, they considered other paths towards a more sustainable energy system to be equally or more important, such as influencing decisions made by companies, organisations, and politicians. Stricter limits than the energy threshold in Ero were suggested by some participants in Study D (see Section 5.2.2 and Paper D). Stricter limits, such as temporary power limits or plugs that only work at off-peak hours, could perhaps emphasise the connection between supply and demand and create a sense of a finite and intermittent supply which might better reflect the actual disposition of an energy system – particularly one that in the future is less fossil-dependent. It should however be noted that intermittent energy supply is common for many people around the globe and for most people this is doubtless an undesirable situation.

Reconnection between supply and demand can be seen as a way of *foregrounding* energy, just as in Interplay, but in Balance the supply of energy or the relation between supply and demand is foregrounded, while households' energy use is typically foregrounded in Interplay.

Sense of participation – not automation

Some of the participants in Study C and Study D were generally positive towards automation (see Papers C and D) and automation was found to be one way to reduce possibilities for users to interact in Reception (see Section 5.3.1). Together with other factors such as invisibility, the automation of heating in terms of thermostatic radiator valves seemed (in Study A) to be an important *frame* of Reception.

Drawing on the insight that automation might contribute unawareness (found in Study A), Ero was designed to require active interaction to support awareness and a *sense of participation*. An example of when active interaction was required was scheduling of smart plugs to times where when there was plenty of the preferred type of energy. The participants in Study D also reflected on more aspects (such as sources of energy) than those directly linked to the service delivered (how warm it was or how infinite the energy supply was) and some of the participants expressed that they appreciated the lack of automation. Other participants in Study D did however wish for more automated functions in Ero.

Automation often implies that assumptions about 'what users want' are made in designs and was discussed also in relation to Reception (see Section 5.3.1). One of interviewees in Study D who tested the home energy management system Green IT Homes (described in IMCG, 2012) reported that this system could not be set at a temperature that was low enough due to incorrect assumptions about what indoor temperature residents want. This could also be an argument for enabling interaction within Balance that could provide a sense of participation, instead of relying on automation.

Influence 'big' decisions

In Study C, some participants emphasised the importance of 'big' steps towards a more sustainability energy future and the 'big' decisions made by industries and governments. Could householders influence these decisions in their capacity as energy users[1]? In Ero, the users were to mark what sources of energy they prefer and if this information was reported to energy companies it could be seen as a way of voicing opinions about energy sources. This information could then be used by energy companies in their decision making. In Study D, the participants did not consider marking sources of energy as a way to influencing 'big' decisions – which was reasonable as this information in Study D was not sent to any energy company. In addition, the way that choices of available sources of energy affected the energy thresholds was not clear to all participants as it was done through a complicated formula.

After evaluation of Ero, some of the participants in Study D seemed more interested in influencing decisions made by companies, politicians, and non-governmental organisations and also in supporting local energy production (see Paper D. In retrospect, Ero should have provided support for these other ways of influencing (as suggested in Section 5.2.2). For example, Ero could have supported local energy production by presenting and suggesting ways of producing renewable energy locally adapted to the household's demands, both in terms of when energy is used (e.g. if it coincides with when solar energy is produced) and how much energy is used (e.g. what capacity is needed).

Everyday energy-reliant activities – not energy-managing activities

One interesting difference touched upon already in the first chapter of this thesis is the difference between energy-reliant and energy-managing activities. The heating devices in the technology probe kit were examples of designs that focused on enabling less energy use *within* everyday energy-reliant activities (cf. Section 2.2.1) and Ero was designed to be used in both energy-reliant and energy-managing activities. Findings from Study C suggested that some participants were interested in reducing their energy use – or the environmental impact from their usage – but not interested in energy *per se*; these participants were not interested in energy-managing activities but willing to adapt their energy-reliant activities. Furthermore, a user who was very interested in energy-managing activities – the interviewee in Study D who wanted to go off-grid – only wanted to know one thing when engaging in energy-reliant activities: if the energy storage units were being charged or used. There thus seemed to be a need for support in adapting energy-reliant activities. Ero was therefore separated into one simpler facet intended to be used in energy-reliant activities and one more complex facet intended to be used in energy-managing activities (see Section 5.1.2).

As reported in Paper D, Ero was integrated into two of the participants' everyday activities. Firstly, as the participants lived in small areas the appliances that the participants wanted to control were never far away. Secondly, Ero was provided to them on tablets that were lent to them. Use of these tablets was less convenient than use of the participants' own smart phones/tablets. Thirdly, as discussed previously, the participants did not find it very meaningful to schedule energy-reliant appliances as they did

1 I have excluded any options related to householders in their capacity as citizens (e.g. voting) as this option did not lie within the scope of research questions 1b and 2.

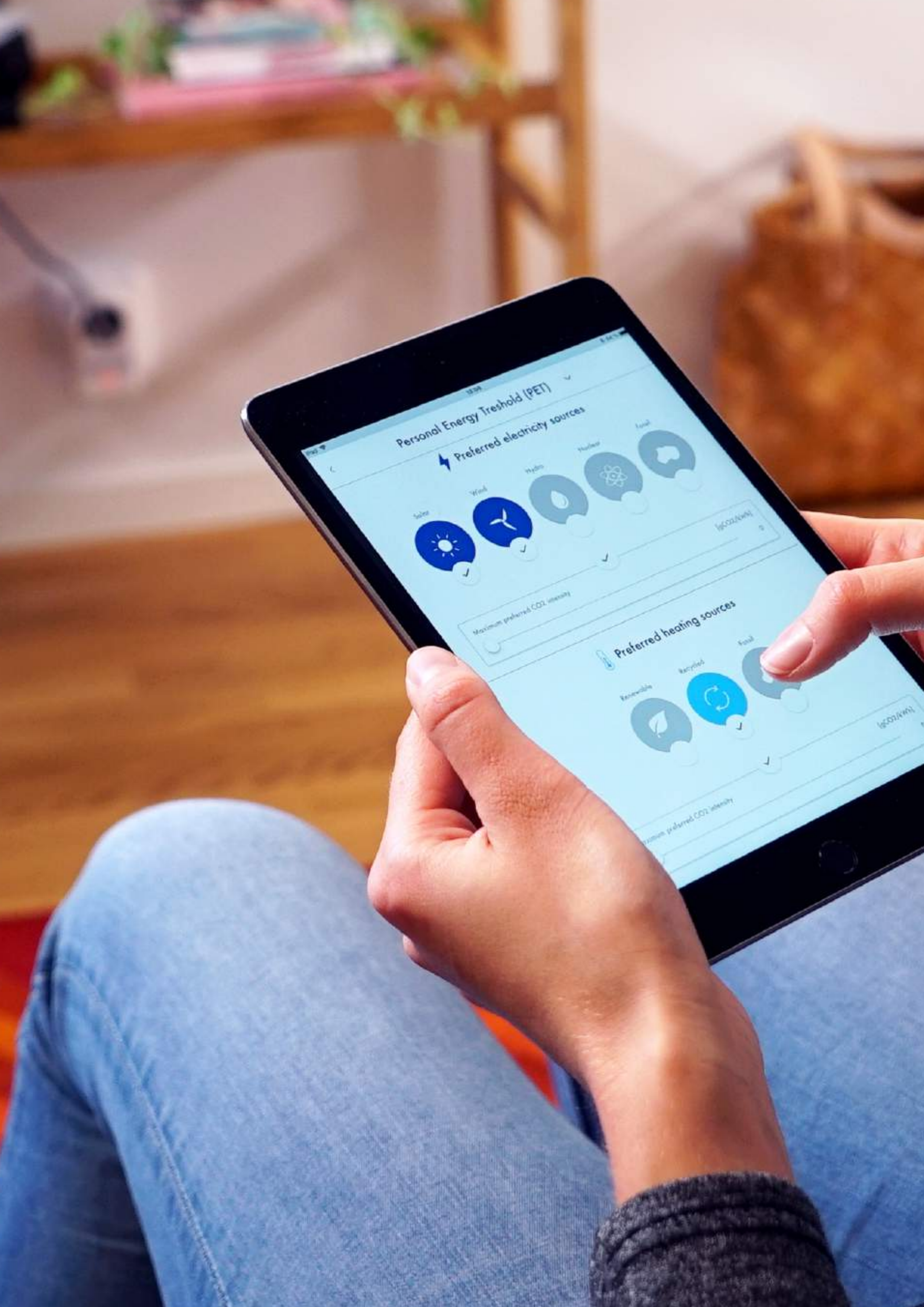
not have so many appliances suitable for time-shifting. Fourthly, the participants did not feel comfortable about scheduling appliances in the common area as they did not want to interfere with someone else's routines. The Activity Organizer concept that preceded Ero included a smart watch app with the simpler facet (see Section 5.1.2). If worn, perhaps this smart watch app could have been more conveniently integrated into everyday energy-reliant activities.

Another important aspect is to communicate *through* the energy service and *within* the energy-reliant activities. Study A revealed that communication about district heating separated from the actual service (e.g. a commercial about district heating's qualities) created awareness and understanding of district heating as a concept or as a phenomenon in the city, but not as the main provider of thermal comfort. As a result, the participants were (to some extent) aware that district heating exists in their living areas, but they were not typically aware of the magnitude of the system, district heating's contribution to the entire energy system, and some of its specific qualities. Such communication might be able to influence energy-managing activities, but seemed, at least in Study A and Study B, not to influence energy-reliant activities. Communication *within* energy-reliant activities – in Study B achieved through the conceptual resemblance between how the heating devices were heated and the functioning of district heating – seemed to have an influence on thermal comfort activities and also increased interest in energy-managing activities (see Paper B).

5.4 SUMMARY

The designing and evaluation of the technology probe kit (Study B) and Ero (Study D) indicated that both energy-reliant and energy-managing artefacts can shape what roles households consider and perform. The prototypes did so either by enabling reduced negative energy-related environmental impact within the meta-roles and thus reproducing the roles or by challenging a meta-role, typically Reception or Interplay, by suggesting acting as within another meta-role, typically Interplay or Balance.

Within each of the three meta-roles, design strategies for reduced negative energy-related environmental impact were identified. Strategies used in Reception include *efficiency measures intended to not be noticed by the user*, measures that *reduce the possibility for the user to interact*, or measures that *reduce the energy service*. Within Interplay designs encouraged reduced negative energy-related environmental impact by *coupling impact reduction to other motives and goals in life*, by *providing more benefits but in an energy-efficient way*, or by *foregrounding energy*. The strategies identified in relation to Balance were uncommon and therefore less verified. The strategies nonetheless suggested were to design to *encourage compromises and ask for efforts*, *reconnect supply and demand*, to *provide a sense of participation* (as an alternative to automation), provide households with a possibility to *influence 'big' decisions*, and to focus primarily on *energy-reliant activities* that are anchored in everyday life and not on energy-managing activities.


Personal Energy Treshold (PET)
Preferred electricity sources
Preferred heating sources

6 DISCUSSION

The previous chapter showed that energy-reliant and energy-managing artefacts – in the shape of research artefacts – can enable reduced negative environmental impact within roles, but also that such artefacts can challenge a prevailing meta-role in favour or a new one. This chapter first presents a reflection on the research approach and the connected processes through which the meta-role roles and connected concepts were created and the research prototypes were designed and evaluated. The findings presented in Chapters 4 and 5 are then reviewed in the light of previous research. Finally, future work needed to build on these findings is suggested.

6.1 REFLECTIONS ON RESEARCH APPROACH

In this section, I will discuss what implications the theoretical and methodological choices had on the findings. First, activity theory – used to inform set-up and analysis of Studies A to D (for reasons presented in Section 2.1.3) – provided constructs necessary to be able to interpret everyday life as roles in energy systems: as ecologies of energy-reliant and energy-managing activities with direct and indirect outcomes for the energy system. The activity-theoretical concept of mediation and the separation of energy-related artefacts into energy-*reliant* and energy-*managing* artefacts that followed were helpful to understand that these need to be designed in different ways (see Section 5.1.2). The Layers of Design framework (see Section 2.2.1) that built on activity theory provided a vocabulary for understanding how characteristics of an artefact as well as the whole set the preconditions for activities and thus also for roles in energy systems. To sum up, activity theory was central to identify roles and to understand how artefacts mediate these roles.

On the other hand, social practice theory was important for the more zoomed-out perspective that made it possible to identify recurring patterns (cf. Spaargaren et al., 2016) and thus to construct and define meta-roles. This theory also brought the idea that practices are shared entities, and meta-roles – here understood as bundles of practices – are thus also viewed as shared, between both individuals and energy companies for instance. Just like a practice, a meta-role is not something individuals change on 'their own' as it goes beyond individuals' doings.

One strength and one weakness with this thesis is its prescriptive and prospective aims. It is a strength as something needs to be prescribed to prospect climate change mitigation. However, based on the complex, dialectic, and non-linear understanding of the world that activity theory and social practice theory provide, it is difficult to make prospective prescriptions. The prescriptions made in this thesis, in terms of the design strategies for reduced energy-related environmental impact aimed at Balance, should therefore not be seen as something that *should* be done, but suggestions for something that *could* be done. Future work is needed to assess the usefulness of these suggestions.

Regarding the methodological approach of this thesis, research through design is still being formed and both methods and processes are under development (Stappers & Giaccardi, 2017). What it is that constitutes research through design-knowledge and how it should be communicated is an ongoing discussion within the field (Gaver, 2012; Höök et al., 2015; Höök & Löwgren, 2012; Stappers & Giaccardi, 2017) and this has also been of importance for this thesis. In accordance with Stappers and Giaccardi (2017), this thesis includes explicit framings of the research prototypes (see Section 5.1). Although the research artefacts demonstrated possibilities, that type of knowledge is not generalisable and therefore not so useful for others in other contexts. Therefore, it was important to also present generalisable insights gained through the design process. Nevertheless, the design processes as such was not recorded and these insights therefore had to be recalled retrospectively. One improvement in the process would be to systematically record such insights.

The use of an integrative research methodology, that is to say application of mixed methods for qualitative and quantitative data collection, was advantageous in all studies as this methodology served as a way of triangulating by methods and by data type (cf. Miles et al., 2014). One limitation however was that the sample sizes were often limited by the methods used for qualitative data, while larger samples would have been required for statistical analyses (see Paper D). Although all empirical studies relied on qualitative and quantitative data, both types of data were self-reported, in other words from the same data source. Inclusion of a secondary data source, such as observations or sensory data, would have improved the credibility of the findings.

One process-related disadvantage following from the iterative nature of thesis writing was that all studies were completed before the meta-role concept was constructed and specific meta-roles were identified. None of the study set-ups were therefore informed by this construct. If that had been possible, it would have been interesting to explore the extent to which the meta-roles were viewed as shared entities, for instance by investigating what external expectations regarding their roles in energy systems that householders perceive. Furthermore, as the meta-roles were defined after the studies, none of the research prototypes were designed with the intention of challenging

Reception or Interplay, nor to suggest acting as within Balance, but were afterwards found to have features interpreted to have done that. The transferability of the suggested design strategies would be clearer if the research porotypes had been designed based on them. On the other hand, inferring strategies from the meta-roles only might have been difficult.

One important limitation to all empirical studies in this thesis concerns the sampling of study participants. Study A aimed for a purposive sample: an average household in the Gothenburg area in terms of type of dwelling, energy use, and environmental opinions. However, I was not able to recruit enough potential participants to enforce any other characteristic than type of dwelling. The number of volunteers in Study B allowed for a spread in environmental opinions, age, and gender. The pre-study questionnaire used made it possible to ensure this spread as these characteristics was known before recruitment and this procedure could be recommended for similar studies. Having said that, even though measures were taken to achieve a purposive sample in Study B, both Studies B and D addressed those who were willing to evaluate new artefacts. This condition suggests that findings from these studies might be transferable only to users with this interest, so-called innovators and early adopters (cf. Rogers, 1995).

The participants in Studies C and D were a non-representative sample of households in Gothenburg as all participants were recruited from a living lab. (See Paper C for a discussion on the ways in which participants in Study C differed from an average household.) These living lab residents could on the other hand be regarded as lead users (von Hippel, 1986), that is users whose current needs will become general in the future. Insights from such users and their perhaps marginal practices can be transferred to general users in different contexts (cf. Ljungblad & Holmquist, 2007).

Another fundamental limitation is the difficulty of establishing whether any influence resulted from use of research prototypes or from research study participation as such. In Study B, the majority of the participants who reported a change were found in the group that used the research prototypes more extensively (see Paper B), which indicates that use rather than the study as such had an influence. In Study D, one participant who did not use the prototype much specifically mentioned that research study participation as such had influenced him. However, changes related to an understanding of private energy use as limited (see Paper D or Section 5.2.2) must have been influenced by the research prototype as that perspective was not brought up as part of the study. The research prototype thus seemed to at least have some influence in Study D.

Zimmerman et al. (2007) have suggested four criteria for evaluating research through design: process, invention, relevance, and extensibility. In judging the *process*, scrutinising the choice of methods and the thoroughness of their employment is key. The strengths and limitations of the process have been highlighted above and in Papers A to D.

The second criterion Zimmerman et al. (2007) mention is *invention*; the design research contribution should be a significant invention. Regarding this criterion, the design phases of Studies B and D had one limitation requirement in common: both phases aimed at designing a prototype that could be built and evaluated *in situ*, which could be argued to also have limited the design space as well as the level of inventiveness. The concepts and ideas preceding the prototypes were less limited and these are therefore presented along with the prototypes, although these preceding concepts/ideas were not completely freed from this requirement. The research prototypes were inventive in their expectations from users – in terms of what additions to motives and goals they enabled (with activity theory terminology) or in terms of what images they expected (with social practice theory terminology) – rather than in aesthetics or technology. In addition, the energy threshold was a new sort of interactive function that can be applied also in other types of artefacts and could maybe be regarded as a *strong concept* (cf. Höök & Löwgren, 2012). If so, it represents one way to achieve extensibility, the extent to which others can build on the outcomes of the results (cf. Zimmerman et al., 2007). The design strategies presented in Section 5.3 were another attempt to allow for extensibility.

In research through design, validity is not regarded as an applicable evaluation criterion and Zimmerman et al. (2007) instead suggest *relevance*. Relevance is created by relating the design to the real world; by motivating the design by grounding it in current situations and preferred future states. Relating research to the Sustainable Development Goals of the United Nations (United Nations, n.d.-a) can be seen as one way of concretising shared preferred future states (as was done in Section 1.1). The research projects that this thesis builds upon were initiated in cooperation with the energy utility Göteborg Energi AB, which provided insights into the local situation as well as a basis for practical application of findings from the research.

6.2 REFLECTIONS ON FINDINGS

This thesis introduced the concept of meta-roles (see Section 4.1) and this concept is discussed in the next section. The specific meta-roles – Reception, Interplay and Balance – and their implications are then examined in relation to previous research. Finally, the usefulness of the design strategies for reduced negative environmental impact suggested in Section 5.3 is reviewed.

6.2.1 Meta-roles & frames

Can the roles householders consider and perform be understood as overarched by meta-roles, which in turn are framed by different aspects – different immaterial and material facets of society? Other researchers have previously understood energy use in everyday life as framed in similar ways. Aune (2007) developed three categories of what a home is – the home as haven, project, and arena for activities – and describes how these homes are domesticated through construction of a network consisting of

"… occupants, activities, technologies and values" (Aune, 2007, p. 5459). In this way, Aune (2007) frames both activities and artefacts in a similar way to the meta-roles presented in this thesis. Goulden et al. (2014, p. 22) use the word 'frame' to describe the roles that households are *expected* to perform in relation to the energy system. Goulden and colleagues use the word 'persona' to describe roles that are enacted from within a person rather than imposed from without (as the frames in their use of the word are). Further, Goulden and colleagues point out that personas and frames co-construct the roles people play in energy systems, similar to the meta-roles and the way they are framed, as described in this thesis. From a field outside of energy use, namely design-driven innovation, Norman and Verganti (2014, p. 82) explain incremental innovation as "improvements within a given frame of solutions" and radical innovation as "a change of frame", where a "frame of solutions" fits well with the concept of meta-roles described in this thesis. The idea of framing in relation to meta-roles thus seems to be used also by other researchers within and outside the field of energy (Aune, 2007; Goulden et al., 2014; Norman & Verganti, 2014). What is the value of understanding roles as parts of framed meta-roles?

Activity theory relies on an understanding of technology and motives as dialectic; they develop with each other (Kaptelinin & Nardi, 2006). The perspective of Norman and Verganti (2014) highlights that this development can be both incremental and radical and that radical innovation entails a shift that, using the concepts developed in this thesis, is a change of meta-roles. The value of meta-roles and understanding them as framed by different aspects may be to see that with incremental innovation, changes will remain within the meta-roles; incremental innovation can enable roles with less negative environmental impact *within* the meta-roles. It may be so that radical innovation is needed to challenge a meta-role. What characterises a radical innovation, apart from a "change of frame"/meta-role (Norman & Verganti, 2014, p. 82)? Findings from Study B suggested that radical innovation could be about asking for efforts and compromises in a new context, such as asking participants to lower their heating and to reuse heating in an inconvenient and time-consuming way. In Study D, reconnecting supply and demand in a context that has focused on demand only seemed to pave the way for considering ways of contributing to a more sustainable energy system beyond the level of the household. The prototypes designed for Studies B and D did not rely on technical innovations (innovative operating concepts) but rather on innovations in meanings and languages, to use the terminology of Verganti (2008). The findings suggested that such innovations could challenge meta-roles as they seemed to develop the motives of everyday activities in a dialectic manner.

Another value of thinking in terms of meta-roles and meta-roles as framed by different aspects is to realise that households alone do not 'own' the question of what roles they should or could play; it is not the households themselves that determine which meta-role that is in play. The challenge of a meta-role cannot be undertaken by households only but needs to be preceded by and/or followed by other actors that shape the aspects: energy companies, municipalities, policymakers, producers of energy-reliant and energy-managing artefacts, academia and so on. Verganti (2008) similarly suggests that a multitude of actors that he calls the *design discourse* 'owns' the question of what meta-role is at play (or which meanings and languages prevail, with Verganti's terminology). Nevertheless, in that discourse, someone has to decide upon a *proposal*, and to present this proposal to users. Who should make that proposal among the multitude of actors in the energy meta-role discourse? In the studies presented in this thesis, the research community (represented by me and colleagues) has in Studies B and D presented the proposal to users. This might evoke less scepticism when suggesting roles that are non-profitable for households but at the same time potentially profitable for energy companies, as both research prototypes suggested. However, as highlighted earlier, although new energy-reliant and energy-managing artefacts could challenge a meta-role (as suggested by findings in Studied B and D) the other aspects of a frame also need to align for the meta-role to change, as illustrated in Figure 6.1. The proposal – and the presenter of the proposal which in this thesis is the research community – therefore needs to be followed by changes in all other aspects that build a frame made by actors with influence over these aspects.

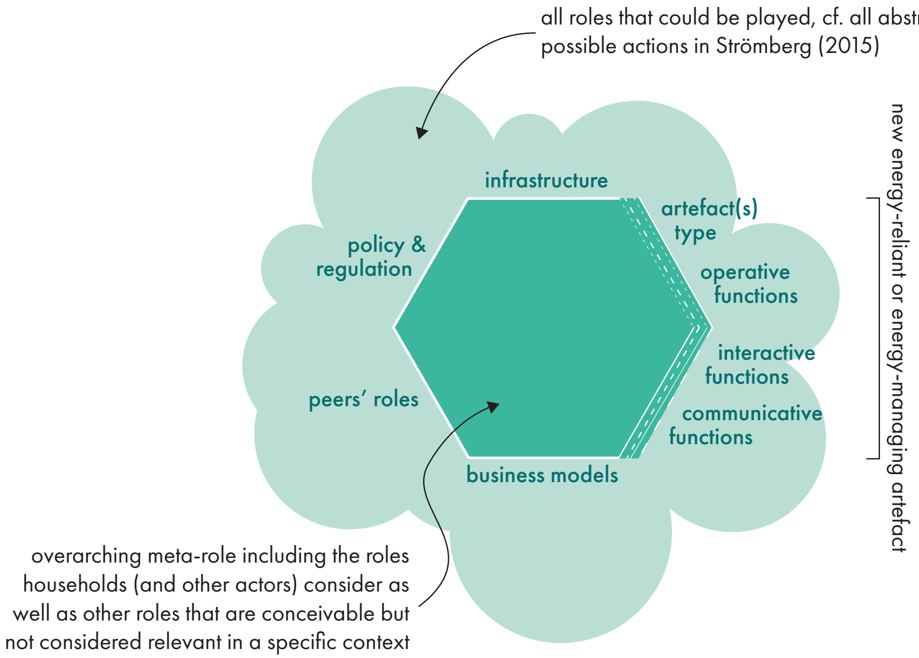


Figure 6.1. *New energy-reliant and energy-managing artefact can challenge which roles could be played of all the roles that are conceivable, that is to say which meta-role prevails. However, to 'complete the frame' and actually change the meta-role, the other aspects need to align.*

A prevailing meta-role was considered to be shared in the sense that all actors in an energy system – including energy companies, householders, regulatory bodies, and energy researchers, for instance – seemed to agree on not only which roles were considered and performed, but also which roles were conceivable. All actors, including users, seemed to find it difficult to think outside this meta-role. I feel that in such situations, user-centred designers (such as myself) have the responsibility to not only design to fit within a prevailing meta-role – if that is the design that users ask for – but also interpret how those user requirements could be manifested in another meta-role (cf. Ljungblad & Holmquist, 2007). Study C showed that it is possible for research participants to imagine a new meta-role, perhaps because imagining of this sort was supported by generative techniques that address not only what people say, do, and think but also what they know, feel, and dream about (cf. Sanders & Stappers, 2012; Sleeswijk Visser et al., 2005). However, not just designing a research prototype for another meta-role (as was done in Studies B and D) but also making such solutions available on the market could be risky as the other aspects would not yet be aligned. Nevertheless, such attempts might be needed to demonstrate that a new meta-role is coming.

6.2.2 Reception, Interplay & Balance in previous research

As argued earlier, the concept of meta-roles as framed seemed to be supported through previous research and there appeared to be some value in using the concept. What can be said about the specific meta-roles identified: Reception, Interplay, and Balance?

Reception involved standardising amounts and variants of the services that energy systems provided. The design strategies for reducing negative environmental impact were (i) efficiency measures not noticeable by users (cf. tacit efficiency in Brand & Fischer, 2013), (ii) efficiency measures by reducing opportunities for user interaction, and (iii) reducing the service. Reception was found to be common in relation to the Swedish district heating system in which heating is often included in the rent and the amount of energy (in terms of heating) was limited by landlords (see Paper A). Although typical for Swedish homes, this situation is in practice similar to many workplaces around the world. Several studies report actions that are in line with those reported in Study A, especially as means of pursuing thermal comfort even when the heating is limited or without control (see Paper A). The similarities between actions reported in Study A and other studies (see e.g. Baker & Standeven, 1996; Karjalainen, 2009; Tweed et al., 2014) indicate that Reception might be present elsewhere too. There are further similarities between Aune's (2007) concept of 'the home as a haven' in the focus on energy-reliant activities and the way of realising them rather than energy as such. Furthermore, the manifestations of an 'energy consumer' persona resulting from the work of Goulden and colleagues (2014) show similarities with Reception. The 'energy consumer' persona had (some) control over energy systems but wished not to think about energy and emphasised that energy is just one of many facets to take in consideration when organising everyday life.

In Interplay, households' meta-role is to optimise their energy services through some kind of interaction with the energy system in favour of their individual preferences, often increased comfort or low cost. Design strategies to reduce negative environmental impact are (i) to couple reduced negative environmental impact to other activities and goals in life, for instance saving money, (ii) to provide more benefits but in a low-carbon way (providing more with less), and (iii) to foreground energy in everyday life. This meta-role resembles Strengers's 'Resource Man' (2014, p. 26) – an energy user who is "interested in his own energy data, understands it, and wants to use it to change the way he uses energy". In smart energy systems, 'Resource Man' is the energy industry's ideal energy user: he is a micro-manager who makes informed and rational decisions that energy utilities can comprehend and anticipate; he is sensitive to price signals as well as data on energy use and environmental impact as simplified metrics (e.g. eco-points of various kinds); and he is interested in energy and energy-efficient technology. Low cost and eco-points are however not the only preferences in Interplay. Other preferences for which to optimise are increased comfort, more light, or added convenience – and some of these preferences were also present in Aune's (2007) conceptualisation of home as a 'project'.

Reflections over individual preferences in relation to what is preferable from an energy system perspective and to (not always but sometimes) act in line with the latter are manifestations of the Balance meta-role. This meta-role does not necessarily include interest in energy as such but requires participation in energy-reliant activities with less negative environmental impact. Design strategies to reduce negative environmental impact are (i) to encourage compromises and ask for efforts, (ii) to make the connection between energy supply and demand explicit, (iii) to provide a possibility to feel like an active participant in the energy system (instead of discouraging active participation through automation) (iv) to provide a possibility for households to influence 'big' energy-related decisions, and (v) to focus on energy-reliant activities rather than energy-managing activities. Several researchers propose concepts in line with Balance, although few of them suggest the dimension of disinterest in energy but interest in contributing by doing one's 'share' (as highlighted in the discussion of Paper C). In relation to the concept of 'the home as arena for activities' Aune (2007) however mentions that "… the inhabitants to a degree seemed to adjust their everyday life routines to the existing material surroundings" which resembles the skill of adapting to and being satisfied with what you get, observed in both Reception and Balance, but not in Interplay. The work of Goulden and his colleagues (2014) resulted in the 'energy consumer' persona and the contrasting 'energy citizen' persona. This latter persona sees and engages with energy as a meaningful part of practices and Goulden and colleagues discuss the idea that community energy schemes and microgeneration technology can be part of shaping 'energy citizens': "Our data has indicated the wealth of change brought about by community energy schemes and by microgeneration technologies in particular. Here, the utility of such schemes should not merely be calculated in terms of energy produced, but also energy citizens produced." (Goulden et al., 2014, p. 28).

To sum up, features from all three meta-roles are present in related research. Nonetheless, the idea that one does not have to be interested in energy to be interested in engaging energy-reliant activities with reduced negative environmental impact seemed to be less present (see Paper C).

6.2.3 Meta-roles & reduced environmental impact

If there are three meta-roles and if artefacts can challenge and reproduce them (see Section 5.2.3), is it therefore possible to determine which meta-roles to attempt to challenge and reproduce for reduced negative energy-related environmental impact? Aune (2007) found that the different ways of domesticating a home that she conceptualised had relevance for both energy use and material consumption. In 'the home as a haven', energy use in terms of heat and light is essential for creating the right 'cosy' feeling. In 'the home as project', energy use and material consumption follow from a continuous renewal of the home. Energy-efficient technology can be a part of that renewal but is not necessarily so as renewal can be optimised for other preferences than low environmental impact or reduced cost – such as increased comfort. In 'the home as arena for activities' the focus is on what you do in the home and not on reshaping the home. Those doings are therefore often undertaken with older technologies and manual labour, which can be more energy-demanding but come with "…a non-spending, non-wasting, environmental-friendly image" (Aune, 2007, p. 5462). The 'Resource Man' might achieve savings within energy-reliant activities, for instance with the use of energy-efficient appliances, but those energy savings tend to be outweighed by increasingly energy-intensive ways of living (Darby, 2008; Strengers, 2014). Goulden and colleagues (2014) summarise that the 'energy citizen' persona holds greater promise for change in favour of lower-carbon lifestyles. These researchers' findings are in line with what I can conclude from the studies presented in this thesis, as presented below.

In Reception, reduced negative environmental impact can be achieved, but only in certain contexts and to a limited degree. To be achieved, households cannot have complete control over their energy use as is the case in most apartments in Sweden. Having said that, the energy service cannot be limited to a degree considered unethical or harmful for householders (cf. Liddell & Morris, 2010; Socialstyrelsen, 2005). As a consequence, some households in Sweden find their apartments too warm and cannot lower the heating enough, especially at night (as found in Studies A and D); for them the energy service is not low *enough*. Tacit efficiency measures may not be intended to be noticed by users. However, tacit efficiency measures (a new district heating plant or other infrastructure, for instance) might be 'noticed' as they are built in cities. In such cases, households in their capacity as residents of the city might need to approve of this investment in some way. Some tacit efficiency measures might therefore require households' support and such support could be difficult to gain if households are unaware of an energy system's contribution to their everyday energy-reliant activities (as elaborated on in Section 4.2.1).

What limits the reduction of negative environmental impact in Interplay is that users always have to gain something from changing their ways of doing and living. When users themselves are very interested in reducing their environmental impact, Interplay might be a fruitful meta-role, although existing designs for households with a strong interest in reducing both their negative environmental impact and energy do not seem to shape long-term engagement (Verkade & Höffken, 2017) (see also the discussion in Paper C). In addition, not all energy users have a strong interest in reducing their environmental impact. For those users, the provision of more benefits but in a low-carbon way (providing more with less) might be a more useful strategy. Such as strategy is however limited to what is technically feasible. Furthermore, one might wonder if that continuous quest for *more* (comfort, convenience, aesthetic, cosiness, etc.) would just continue to support the tendency to adopt more and more energy-intensive ways of living (cf. Darby, 2008; Strengers, 2014).

It is difficult to determine what could be gained in terms of reduced negative environmental impact in Balance as this meta-role is uncommon. The evaluation of Ero, to some extent the technology probe kit, and the interviewees interviewed in the design phase of Study D suggested an interest in limits to energy use where the limits are in one way or another controlled by households themselves. Such limits would not have to be considered as harmless for all, as in Reception, since they can be adapted to a household's specific preferences and preconditions. The idea of personalised limits is supported by Nyborg and Røpke (2013) who found that acceptance of variation in indoor temperature was higher than the pre-determined limits in an artefact set by the project team, partly due to specific preconditions such as access to a fireplace as an alternative heat source. The appreciation of the energy threshold in Study D suggested that households might not only be interested in efficiency; they might want to start thinking in terms of *sufficiency*. The evaluation of Ero further suggested increased interest in influencing the energy systems through other ways than just how energy is used and what energy-reliant and energy-managing artefacts are bought and used. In addition, interest in local energy production seemed to increase in Study D. This interest could perhaps also increase acceptance of investments in energy systems that are not quite as local (as discussed earlier), but this connection remains to be verified.

To sum up, there are ways to reduce negative environmental impact within all meta-roles, as described in Section 5.3. However, in Reception such attempts could run the risk of resulting in non-efficient workarounds (see Paper A) and can be regarded as unfair: a specific indoor temperature, for instance, affects people differently as we all have different physical preconditions (cf. Socialstyrelsen, 2005, among others). In Interplay, reductions in negative environmental impact are limited to different kinds of win-win-situations. With the major transformations that are needed to mitigate climate change, it is not certain that all required changes can become win-wins.

Instead of aiming for 'more with less', we might have to be satisfied with 'less with even less'. In Balance, households are expected to make compromises and in that sense accept 'less' and therefore seems like the most promising meta-role from this perspective. However, it is yet to be explored if and how that meta-role could become as common as Reception and Interplay.

6.2.4 Design strategies for energy-reliant & energy-managing artefacts

As suggested in this discussion, radical innovations in meanings and languages could contribute to incorporating a new motive into existing activities. If so, how to design in a way that challenges Reception and Interplay and supports the type of motives (cf. Figure 4.10, 5.6, and 5.7) found in Balance? Five potentially useful design strategies were suggested in Section 5.3.3. The first strategy was to suggest that householders should make compromises and to ask for efforts. To have any success with such a strategy principle, compromises and efforts should be perceived as meaningful. Careful design of effortful interactions could be crucial to become a meaningful experience (cf. Lenz et al., 2013). Inspiration could come from effortful energy-managing activities that in contexts where they are (more or less) voluntary are already perceived as meaningful, such as chopping wood and lighting fires. Precisely these activities also represent one way of materialising the second principle: to reconnect energy demand and supply. Another way of reconnecting supply and demand seemed to be through local energy production: community energy schemes and microgeneration technologies (cf. Goulden et al., 2014). In Ero, the attempt was to reconnect not only to local supply (in terms of wood or for example PV panels) but also to connect city-scale energy systems to demand. It seemed as if Ero, for some participants in Study D, was able to support such a connection. The extent to which they could contribute was however limited (see Section 5.3.3) and they wanted to influence decisions by companies, politicians, and non-governmental organisations (see Paper D). Reconnection of supply and demand thus might have other consequences than only influencing demand.

The findings in Study A highlighted the disinterest in energy and unawareness of the energy systems (in that case district heating) that can follow from disconnecting and excluding energy users from the energy system through automation (see Paper A), for instance. Although interest in energy as such is not a necessity for Balance, as previously discussed, some basic awareness might be necessary for interest in reducing negative environmental impact in relation to energy-reliant activities. This basic awareness could be supported by designing for a sense of participation instead of hiding and discouraging participation through automation. In addition, automation has previously been found to reduce a sense of personal responsibility (Murtagh et al., 2015).

Participation can also be about influencing 'big' decisions related to local, national, or maybe even global energy systems. Prost et al. (2015) consider that design, and particularly interaction design, could – and should – enable people to reach out to political and economic stakeholders, but conclude that this is an understudied area of design. While some companies sometimes try to display their environmental concerns and actions (so-called 'green-wash'), other efforts are undertaken without much publicity directed at households (cf. tacit efficiency). In Reception, households are not considered to be interested in such information. In Balance, communication about such efforts might support the sense that the 'big' players are doing their 'share'. Transparency and trust between different actors in the energy system are important, as pointed out by Hasselqvist (2018). Transparency and trust may further be more difficult for private energy companies to achieve than for other types of organisations, such as community energy schemes (as discussed by Goulden, Spence, Wardman, & Leygue, 2018).

The final strategy is to focus primarily on energy-reliant activities in everyday life and not on new energy-managing activities that are not anchored in this complex web (cf. Strengers, 2011). This suggestion follows from the finding that participants in Study B who changed their thermal comfort activities (an energy-reliant activity) did so without any preceding energy-managing activity. Instead, some of them started to engage in some energy-managing activities after alterations of their energy-reliant activities. Goulden and colleagues (2014) found that the 'co-management of practices' (here interpreted as alterations of energy-reliant activities) that Strengers (2011) asks for was achieved through co-management of resources (here interpreted as alterations of energy-managing activities). Findings from Study B propose that the opposite is also possible.

These strategies concern the design of energy-reliant and energy-managing artefacts. However, artefacts are just one of the five aspects found to frame meta-roles. Artefacts can therefore perhaps challenge a meta-role, but the other aspects will need to align to change a meta-role. Some attempts to design for a non-prevailing meta-role might fail due to misalignment with the other aspects. Studies B and D provided an example of that. The current business model in which households directly or indirectly pay for the amount of energy they receive could have undermined the technology probe kit and Ero if these prototypes had been provided to the participants by an energy company as the participants' compromises and efforts would have economically benefited the energy provider, and not the participants. In practice, this became less of a problem as these artefacts came from the research community and were communicated as research prototypes, but the issue was discussed especially by participants in Study B.

To sum up, findings primarily from Studies B and D suggest that when they are in use, energy-reliant and energy-managing artefacts can initiate a process of changing a prevailing meta-role, at least when such artefacts are introduced to householders by the research community. It would therefore appear that in the long run, design seems to have consequences for which meta-role prevails and this, in turn, has implications for the extent to which negative environmental impact from the energy system can be reduced.

6.3 FUTURE WORK

Future work is needed to clarify in what context some of the findings presented in this thesis can be transferred and the extent to which they can be generalised, as indicated in the reflections on the research approach (see Section 6.1) and elaborated on in this section. Previous research could also be applied to some of the findings to make them more useful, as the following reflection will show.

Regarding some findings, such as what specific roles were considered and performed conceptualised from purposive but non-random (Study A) and non-representative (Study C) samples, it would be useful to know the distribution in the whole population (i.e. all households in Gothenburg). Based on the findings from Studies A and C quantitative studies could be designed (cf. exploratory sequential mixed methods in Creswell, 2014)California</pub-location><publisher>Sage</publisher><urls></urls></record></Cite></EndNote> and performed with the aim of drawing statistically significant inferences to the whole population. If commercial artefacts are to be designed for these roles such knowledge would be necessary to assess market potential.

The transferability of meta-roles as a construct could be explored by trying to identify meta-roles in other contexts, such as transport or consumption. I would assume that the five aspects found to frame meta-roles are not transferable, but some of them probably would be. Furthermore, the potential usefulness of the meta-roles suggested in the reflections on findings needs to be validated (see Section 6.2.1) both in academia and in industry.

The Balance meta-role was uncommon in relation to current energy systems but was discussed in relation to a more sustainable energy future. The extent to which the roles within Balance would not only be considered but also performed therefore needs to be explored. Not all participants in Study C seemed interested in Balance, so it remains to be seen if this meta-role is suitable for everyone. Balance's potential for reduced negative energy-related environmental impact should additionally be validated as it has not yet been possible to evaluate this during the course of this thesis.

The design strategies for reduced negative energy-related environmental impact aimed at Balance were inferred from the research prototypes designed as part of Studies B and D and from a few concepts and artefacts available on the market. The generalisability of these design strategies would therefore have to be evaluated for other types of artefacts, designed by other designers, intended for other users, and finally tested by other participants. As the design strategies for reduced negative energy-related environmental impact within Reception and Interplay were based on concepts and artefacts on the market, their validity is considered to be higher.

Apart from energy-reliant and energy-managing artefacts, four aspects were found to frame meta-roles. In the reflection on the findings (see Sections 6.2.1 and 6.2.4) I therefore point out that for a prevailing meta-role to change, these aspects need to also align to the upcoming meta-role. This thesis does not study what this alignment entails or the processes through which alignment could happen. Insights from the field of technological transitions, especially the multi-level perspective (cf. Geels, 2002) and sustainability transitions (cf. e.g. Verbong & Loorbach, 2012) could be used to improve this understanding. Alternatively, meta-roles, aspects, and frames could be understood with the constructs provided by transition theories. Nonetheless, some of the nuances that the meta-roles provide might be lost with the grander and more longitudinal perspective of transitions.

As suggested by participants in Study D, the Ero research prototype would have fitted better in another context, such as in a detached house with several residents (e.g. a family) with an electric vehicles or other artefact with significant energy use. A future study could be to evaluate Ero in such as setting. On a more detailed note, the energy threshold is an interactive function worthy of further exploration. (See Figure 6.2 for another version of an energy threshold user interface designed for the concept Activity Organizer, see Section 3.3.5) The idea of having a limit on energy use, even stricter than the one in the version of Ero that was evaluated, was appreciated by most participants. In addition, this idea of limits fits with the idea that energy efficiency will not be enough – we must also think in terms of energy sufficiency (cf. Darby & Fawcett, 2018). At the same time, commercial artefacts are introducing limits on environmental impact, such as credit cards with carbon limits which will be launched (Doconomy, 2019). Future work could include exploring if and how such limits on consumption could be a way of making complex sustainability issues actionable in everyday life.

Finally, this thesis focused on energy-reliant and energy-managing artefacts *when* they are embedded into everyday life (see the aim in Section 1.2). How they *become* adopted/appropriated has not been studied although that is a necessity for being embedded. Strömberg (2015) and later Babapour (2019) showed that the adoption/appropriation processes in the contexts of new modes of traveling and shared office spaces need to be supported. The adoption/appropriation processes of new energy-reliant and energy-managing artefacts could be explored to find out if they would need similar types of support.

Figure 6.2. *Two facets of another version of an energy threshold user interface designed as a part of the concept Activity Organizer (see Section 3.3.5). A smart watch might be easier to integrate into energy-reliant activities than a tablet is, as discussed also in Paper D. Image by Boid AB (reprinted with permission).*


ELECTRICITY
Washing machine
DISTRICT ENERGY

Image of the Activiy Organizer (see Section 3.3.5). Image by Boid AB (reprinted with permission).

7 CONCLUSIONS

The title of this thesis – Participating in Energy Systems through Everyday Designs – guides this conclusion. The first half initiates the concluding answer to research question 1a as the roles and meta-roles identified represent different ways of ***participating in energy systems****. The second half of the title also marks the start of the answers to research questions 1b and 2. These answers show how energy-reliant and energy-managing artefacts can enable roles and challenge meta-roles, and thereby the potential for reduced negative environmental impact or, in other words, how different ways of participating in energy systems are enabled* ***through everyday design****.*

7.1 PARTICIPATING IN ENERGY SYSTEMS...

RQ 1a. What roles could householders, in their everyday lives, play in district heating systems, smart energy systems, and combinations of the two?

The findings showed that participants considered and performed a variety of roles, but this variety was at the same time framed by (i) what roles others are playing, (ii) energy-reliant and energy managing artefacts that are accessible, (iii) what business models are common, (iv) available infrastructure, and (v) policy and regulation. As these aspects are different for district heating systems and smart energy systems, the played roles were also typically different. These aspects framed three so-called meta-roles into which the considered and performed roles fitted.

- Reception results in standardised amounts and variants of services from the energy system, through a pre-set indoor temperature for instance. In this way of thinking, households are not expected to be interested in anything other than the service as such. This meta-role was especially common in relation to district heating in apartments.

- In Interplay, households are expected to use some kind of interplay with the energy system to optimise their energy services for their individual preferences, for example low cost, increased comfort, or more convenience. This meta-role prevailed in the context of energy use, both in apartments and in detached houses.
- In the final meta-role, Balance, households are expected to be willing to balance their individual preferences with what is preferable from an energy system perspective, for instance without the benefit of being part of time-shifting energy use to cut peaks in demand. Balance was uncommon in current energy systems but common as participants discussed their roles in future more sustainable energy systems.

The three meta-roles identified seemed to have different potential for reduced negative environmental impact.

- Reductions in Reception are limited to what can be achieved without households' active contribution. Reductions are further limited to what can be seen as fair and ethical for all and therefore miss opportunities that are applicable only to some households.
- Any reductions in Interplay are restricted to when personal benefits can be aligned with reduced negative energy-related environmental impact – and low cost is an example of this – or when households themselves want to reduce their negative energy-related environmental impact.
- The potential for reductions in Balance is difficult to determine as there is little empirical material (in this thesis and in other studies). However, the findings suggested that households could start thinking more in terms of energy sufficiency, rather than energy efficiency, and could consider supporting local production of renewable energy.

7.2 … THROUGH EVERYDAY DESIGNS

RQ 1b. How do energy-reliant and energy-managing artefacts shape what roles householders consider and perform?

RQ 2. In view of the roles householders consider and play in energy systems, how could design of energy-reliant and energy-managing artefacts shape the potential for reduced negative environmental impact?

Energy-reliant and energy-managing artefacts, understood as structured in layers, were found to be one of the aspects that framed meta-roles. In terms of reduced negative energy-related environmental impact, re-design of both energy-reliant and energy-managing artefacts could enable roles with less impact *within* one meta-role and also *challenge* a prevailing meta-role with limited potential for reductions. For both Reception and Interplay, the two common meta-roles at the time of the research, a number of design strategies that could enable roles with less impact *within* these meta-roles were identified from both academia and industry. Among these, the design strategies that fitted with Reception were:

- efficiency measures not noticeable by users;
- efficiency by reducing opportunities for user interaction; and
- reduction in the amount of the service, for example reducing indoor heating.

Design strategies to reduce negative environmental impact within Interplay were:

- to couple reduced negative environmental impact to other activities and goals in life, for instance saving money;
- to provide more benefits but in a low-carbon way (providing more with less); and
- to foreground energy in everyday life.

In order to challenge both Reception and Interplay and to design for reduced negative energy-related environmental impact within Balance, the following design strategies were to some extent evaluated through two research prototypes. Based on these evaluations, the following strategies are suggested although they require testing to confirm their usefulness.

- Encourage householders to make compromises and ask for efforts.
- Design in a way that makes the connection between energy supply and demand explicit ('reconnect' supply and demand).
- Provide a possibility for householders to feel like active participants in the energy system (providing a sense of participation instead of discouraging that sense through automation).
- Provide a possibility for households to influence energy-related decisions made by companies or authorities locally, nationally, and maybe even globally.
- Focus primarily on energy-reliant activities in everyday life and not only on new energy-managing activities that are not anchored in the complex web of everyday activities.

As mentioned, artefacts are just one of the five aspects that were found to frame meta-roles and the other aspects need to align to change meta-roles. Having said that, the findings from this thesis indicate that artefacts can challenge a meta-role. Artefacts could therefore influence which meta-role prevails and, consequently, have implications for the extent to which negative energy-related environmental impact can be reduced.

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